Agreement on the Conservation of Albatrosses and Petrels

**Thirteenth Meeting of the Seabird Bycatch Working Group**

*Swakopmund, Namibia, 27 - 29 May 2026*

# Assessing the effectiveness of seabird bycatch mitigation in New Zealand large vessel trawl fisheries

***New Zealand***

## SUMMARY

The large vessel trawl fleet continues to account for a high proportion of bycatch risk to several seabird species in New Zealand despite extensive efforts to reduce the attraction of fishing activities to seabirds and to mitigate seabird warp strikes. Mandatory mitigation requirements include the use of bird scaring lines, bird bafflers or warp scarers, and the fleet has had robust observer coverage for over 20 years. To enable further reduction of seabird bycatch in these fisheries, research was commissioned to firstly assess the relative effectiveness of bycatch mitigation options used in the fleet, and secondly to develop protocols for improved data collection going forwards.

Large et al (2024) used existing observer data to assess the use and effectiveness of warp mitigation measures currently in use. Whilst the study concluded that bird scaring lines were more effective than bird bafflers, the findings were limited by various limitations and challenges associated with the data set compared to experimental study data sets. Accordingly, a number of recommendations were made to improve the collection of data on-board fishing vessels by fishery observers. This included ensuring that both the use of mitigation devices and their configuration are recorded in a consistent way, clearly distinguishing between the lack of device use and the lack of a record of device use, collection of bird abundance and activity data (as proxies for bycatch risk), consistent recording of the discharge of fishing waste and use of onboard cameras.

Based on these recommendations, English (2026) developed and tested a range of data collection protocols on a large vessel trawl fishing trip, suitable for assessing both warp strike and net capture mitigation. This included using a temporary camera placement which could be placed to record bird activity in areas astern of the vessel where observers cannot readily access due to safety constraints. A protocol was proposed for wider trial across a representative range of vessels in the fleet.

**Attachments:**

Large, K. and Berkenbusch, K. and Richard, Y. and Neubauer, P. 2024. Warp strike mitigation in large-vessel trawl fisheries in New Zealand. Final report prepared for Department of Conservation. 33 p.

English, J. 2026. Protocols for large vessel trawl seabird bycatch mitigation data collection: progress report on initial at-sea trial. Report prepared for Department of Conservation, Project MIT2025-06.

# Warp strike mitigation in large-vessel trawl fisheries in New Zealand

Final report prepared for Department of Conservation – October 2024

**Authors:**
Kath Large
Katrin Berkenbusch
Yvan Richard
Philipp Neubauer

DRAGONFLY
Data Science

PO Box 27535, Wellington 6141
New Zealand
dragonfly.co.nz

## Cover Notes

To be cited as:

Large, K. and Berkenbusch, K. and Richard, Y. and Neubauer, P. (2024). Warp strike mitigation in large-vessel trawl fisheries in New Zealand. Final report prepared for Department of Conservation. 33 p.

# CONTENTS

# EXECUTIVE SUMMARY

Efforts to prevent seabird interactions with commercial fisheries include the use of bycatch mitigation devices during active fishing operations. In New Zealand, mandatory mitigation requirements for trawl fishing by large vessels (≥28 m length) include the use of at least one of three types of mitigation device, bird scaring (tori, streamer) lines, bird bafflers, or warp scarers (warp deflectors). During fishing operations, fisheries observers record information pertaining to the use of these mitigation devices, including seabird interactions, such as incidental captures. These data were used in the current study in an initial exploration aimed at characterising the use of mitigation devices in large-vessel trawl fisheries. This data exploration also included an assessment of seabird captures in relation to mitigation device type. The analysis was limited to warp captures, omitting records of net captures. The characterisation also considered the configuration of mitigation devices used across different large-vessel trawl fisheries.

The present assessment included statistical modelling to examine whether the use of mitigation devices influenced seabird capture rates. This part of the analysis used generalised linear mixed models to estimate capture rates from fisheries observer data. Covariates included in the models were fishing year, fishery, area and vessel as random effects, with mitigation gear included as a categorical fixed effect (at levels baffler-only, tori-line-only, baffler-and-tori-line).

The characterisation of warp mitigation devices showed that bird bafflers were the most prevalent mitigation gear used in large-vessel trawl fisheries. In addition, there was an increase in the use of this mitigation gear type over time. Bird bafflers in combination with tori lines were also used on a comparatively high number of tows, followed by the use of tori lines. There were only limited observer records of warp strike mitigation using warp scarers or other combinations of mitigation gear. These data were insufficient to be included in the statistical modelling.

Comparing the effectiveness of mitigation devices with bird bafflers as the reference indicated that tori lines were more effective than the former mitigation device type. The combination of bird bafflers and tori lines was slightly less effective than the use of bird bafflers only, but this finding was inconsistent across models. It may also be confounded by varying mitigation requirements; e.g., the use of multiple mitigation types required during “high risk” periods when there are more birds foraging such as during the peak squid trawl season. In addition, the modelling suggested that the effectiveness of bird bafflers has improved, especially after 2015. The inclusion of data that describes mitigation device gear changes (in both design and configuration) over time.

For the analysis of the configuration of mitigation gear, there was considerable variation in the amount of information available in the observer records. In addition, a high number of unique configurations of mitigation devices used during fishing prevented the analysis of particular configurations in relation to seabird captures.

Highlighting these limitations and challenges, recommendations from the present study include the exploration of different analysis techniques to assess the diversity of gear configurations. These techniques include clustering algorithms and dimensionality reduction, to group configurations of mitigation gear into consistent sets. The configuration groups can then be used to assess differences in bycatch rates, while taking into account the relative abundance of seabirds. The latter may also include the use of seabird count data that are regularly recorded at the back of fishing vessels. In addition, in-depth analysis of mitigation gear data may be augmented by including data on vessel waste management.

To provide context for the analysis, the current project also included a comparison of the three mitigation devices, based on existing information. Although there has been ongoing research into the use of different mitigation devices for a number of years, relatively few studies provide sufficient information to support formal analyses of their efficacy. Most research has focused on assessing the effectiveness of bird scaring lines, with findings consistently indicating a reduction in warp strike associated with their use across different trawl fisheries. Based on this evidence, and consistent with the model results in this study, bird scaring lines are the only mitigation device type included in the recommendations of best-practice mitigation measures by the Agreement on the Conservation of Albatrosses and Petrels.

# 1. INTRODUCTION

At-sea interactions with commercial fisheries can lead to the injury and incidental capture of seabirds, frequently resulting in bycatch mortality (e.g., Clay et al. 2019). On a global scale, bycatch has been identified as one of the main threats for a range of seabird species and populations, including endangered and threatened albatrosses and petrels (Phillips et al. 2016, Dias et al. 2019). At the same time, the recognition of bycatch impacts has led to increasing efforts to prevent or reduce interactions between seabirds and commercial fishing operations. Mitigation efforts have included operational changes in fishing practices and the development of techniques and measures that deter or prevent seabirds from interacting with fishing vessels and gear (Pierre et al. 2012, Favero & Seco Pon 2014, Goad & Williamson 2015).

In New Zealand, one of the main goals of the "National Plan of Action – Seabirds 2020" is the prevention of seabird bycatch through the use of effective mitigation (Fisheries New Zealand and Department of Conservation 2020). The latter includes non-regulatory "best practice" approaches and mitigation standards across different commercial fisheries (e.g., Plencner 2023), and also mandatory measures, such as for large-vessel trawl fisheries (defined as vessels that are at least 28 m in overall length; New Zealand Government 2010). Regulatory measures in these fisheries require the use of one of three types of seabird scaring device, with specific requirements for each device: bird scaring lines (i.e., paired streamer or tori lines), bird bafflers, or warp scarers (i.e., warp deflectors). All three devices are aimed at preventing seabird interactions with trawl cables (warps), as warp strike poses one of the main risks associated with seabird interactions in trawl fisheries.

Ongoing monitoring data pertaining to the use of mitigation devices are available from fisheries observers, who record information on protected species interactions and mitigation measures while onboard commercial vessels. These observer records have been used in previous analyses of mitigation measures in New Zealand trawl fisheries (Abraham & Kennedy 2008, Abraham & Thompson 2009). In addition, there have been qualitative and experimental studies focused on the use of mitigation techniques aimed at preventing warp strike in New Zealand waters (e.g., Middleton & Abraham 2007, Cleal & Pierre 2012b).

Since the introduction of mandatory warp mitigation devices in large-vessel trawl fisheries in 2006–07 and other mitigation measures, there have been some declines in estimated seabird captures and capture rates; however, bycatch estimates have remained variable overall, including in recent fishing years (Abraham & Richard 2020).

This variability in seabird bycatch provided the impetus of the present project "to assess the use and effectiveness of warp mitigation measures currently in use across New Zealand's commercial large-vessel trawl fisheries." The assessment was based on an initial exploration and analysis of observer data across vessels and target fisheries, and included a review of existing information regarding the effectiveness of warp strike mitigation measures.

# 2. METHODS

The initial data exploration and analysis focused on a characterisation of data recorded in the Centralised Observer Database (COD). The characterisation examined seabird capture rates across different large-vessel trawl fisheries in relation to observer effort. This part of the assessment was based on observer data for the period from 1992–93 to 2019–20. Prior to the introduction of mandatory mitigation measures in January 2006, the use of mitigation devices followed a voluntary code of practice, and early data may contain some inconsistencies; however, data from this period were included in the initial exploration.

The current assessment also included the configuration of mitigation devices used in large-vessel fisheries, and exploration of these data for the analysis of seabird captures. Further analysis focused on the assessment of seabird capture rates in relation to recorded warp mitigation device types. These analyses included data from the period following the mandatory introduction of mitigation measures in 2007 (i.e., from 2007–08 to 2019–20) onwards.

To provide context for the analysis, a review of existing information focused on studies that assessed the effectiveness of these warp mitigation devices in trawl fisheries.

Throughout this report, bird scaring lines and warp deflectors are also referred to as tori lines and warp scarers, respectively.

## 2.1 Review of existing information

The review of existing information was based on a systematic literature search of research and studies that assessed the efficacy of each of the three types of seabird mitigation device in trawl fisheries. The search for information was primarily based on published reviews and individual research publications (including cross-referencing), with a particular focus on recent publications (i.e., since 2015), building on earlier reviews (e.g., Bull 2007, Parker 2017, Sacchi 2021). The search focused on a number of databases and internet search engines: Aquatic Sciences and Fisheries Abstracts (including Biological Sciences, Biology Digest, BioOne.1, Conference Papers Index, Ocean Abstracts, Scopus Natural Sciences), Science Direct, Ornithological Worldwide Literature (includes coverage of grey literature), Searchable Ornithological Research Archive, Google, and Google Scholar.

Keywords for each mitigation device were searched individually or in combination; e.g., search terms for tori lines included *seabird, trawl*, mitigat*, tori, streamer, bycatch, warp, strike, bird, scar*, BSL; the initial search was narrowed using key words such as effective*, test, and trial.

## 2.2 Relative effectiveness of warp mitigation gear

The analysis of observer data was based on the development of existing models used for the estimation of seabird bycatch (see Abraham & Richard 2020). These models were initially developed to estimate seabird capture rates by fishery group and area based on observer data. Mitigation gear type was not previously included in these models. The models were, therefore, expanded to allow the inclusion of covariates for the three types of mitigation device—tori lines, bird bafflers, and warp scarers. Modelling examined whether the use of these mitigation devices affected seabird capture rates. The analysis was limited to warp captures, distinguishing their records from records of net captures.

The modelling was aimed at identifying the effectiveness of device combinations based on available data. Gear configuration data were considered too sparse and inconsistently recorded to allow more detailed modelling. For this reason, only the mitigation gear type recorded for each trip was used in the analysis. Data included records for the fishing years from 2008–09 to 2019–20. Records without information of warp mitigation gear and where mitigation gear was indicated as “none” were excluded from the analysis.

Capture rates were estimated from observer catch rates using generalised linear mixed models. The covariates included in the model were fishing year, fishery, area and vessel as random effects, with mitigation gear included as a categorical fixed effect (at levels baffler-only, tori-line-only, baffler-and-tori-line). Interactions of gear type with year and vessel were used to assess the consistency of mitigation gear effectiveness over time and across vessels. Candidate models were developed to include a range of these factors, from simple models including only mitigation type, to more complex models that considered fishing year, area, fishery group, and the interactions of gear and vessels and fishing year (Table 1).

Models were estimated within the general Bayesian linear model framework "brms" (Bürkner 2018). A negative binomial model was used, which is preferred for highly skewed discrete distributions with considerable numbers of zeros. The models fit estimates of capture rates (captures per tow), with a negative parameter estimate indicating a reduction in capture rate.

Models were fitted with eight separate Markov Chain Monte Carlo (MCMC) chains with 3000 iterations, including a 1000 iteration burn-in period that was discarded from posterior samples. Convergence was assessed by marginal and multivariate scale reduction factors (MSRF) across the eight chains (at convergence of MCMC runs, the MSFR (or $\hat{R}$) is one). Model fit was evaluated by posterior predictive checks and Leave-One-Out information criterion (LOOIC; Vehtari et al. 2017) comparisons between models. The model with the best LOOIC was taken to be the model which best explained observed capture rates.

**Table 1:** Candidate models for seabird capture rate (captures per tow) in relation to mitigation gear type, fishery group, vessel, year and area, and their interaction effects.

| Model | Formula |
|---|---|
| 1 | mitigation_type |
| 2 | (1 \| area) + mitigation_type |
| 3 | (1 \| Fishery Group) + (1 \| area) + mitigation_type |
| 4 | (1 \| vessel) + (1 \| Fishery Group) + (1 \| area) + mitigation_type |
| 5 | (1 \| fyear) + (1 \| Fishery Group) + (1 \| area) + mitigation_type |
| 6 | (1 \| fyear) + (1 \| vessel) + (1 \| Fishery Group) + (1 \| area) + mitigation_type |
| 7 | (1 \| fyear) + (1 \| vessel) + (1 \| Fishery Group) + (1 \| area) + mitigation_type + (1 \| vessel:mitigation_type) |
| 8 | (1 \| fyear) + (1 \| vessel) + (1 \| Fishery Group) + (1 \| area) + mitigation_type + (1 \| fyear:mitigation_type) |
| 9 | Model 8 + (1 \| vessel:mitigation_type) |

### 2.3 Configuration of warp mitigation devices

Since 2007, fisheries observers have recorded the configuration of mitigation devices, including characteristics such as type, material, colour, and length. These records are stored in COD (Sanders & Fisher 2022).

Observers generally record the information about each device at the start of the fishing trip, and update it if necessary, e.g., when the device gets damaged. The characteristics recorded about a device depend on its type, and are stored in separate tables in COD, in tables *x_tori_line*, *x_bird_baffler*, and *x_warp_scarer*, for tori lines, bird bafflers, and warp scarers, respectively.

These data (from 2008–09 to 2019–20) were analysed as part of the current study, providing information of the characteristics across the different mitigation devices used.

# 3. RESULTS

## 3.1 Review of warp mitigation devices

Efforts to prevent seabirds from interacting with trawl (and other) fisheries have led to a range of studies focused on different mitigation approaches. Research has encompassed experimental studies and trials, anecdotal data collections, and analyses of fisheries observer data, including from New Zealand (Cleal & Pierre 2012a, Pierre 2018). Across studies, the most significant mitigation measure identified in bycatch research has been the management of fish waste, such as offal and discards, which attracts seabirds to the proximity of trawl gear at the stern of the vessel (e.g., see Abraham et al. 2009, Favero et al. 2011, Pierre et al. 2012, Kuepfer et al. 2022). Based on this research, the retention of waste has been highlighted as one of the most important best-practice mitigation measure, substantially reducing the attendance of seabirds during active fishing operations (Agreement on the Conservation of Albatrosses and Petrels 2023).

For specific studies of mitigation devices, qualitative and quantitative research has generally focused on particular trawl fisheries, assessing different types of mitigation device and their configurations and designs (e.g., see Melvin et al. 2011, Melvin et al. 2013, Sullivan et al. 2006). Although this research has been ongoing for a number of years, relatively few studies provide sufficient information to formally analyse the efficacy of different mitigation devices or to corroborate findings from at-sea trials and previous studies (but see for example Maree et al. 2014). In addition, there may be differences in trawl gear across studies so that the efficacy of mitigation devices may be specific to the fleet, fishing operations, or seabird species (e.g., see Løkkeborg 2011). These differences make it difficult to determine a universal mitigation device or design that is effective across all trawl fisheries. Similarly, the concomitant use of other mitigation measures (such as waste retention) in some studies means that observed decreases in seabird captures cannot always be attributed to a single device or measure. Nevertheless, existing research provides some overall distinction across the three device types included in the present study.

This aspect was also highlighted in a recent review of seabird bycatch mitigation measures for New Zealand commercial fisheries (Parker 2017). This review provides information across a range of mitigation approaches, including experimental studies and trials, with an appraisal of their efficacy. Across the three mitigation device types included in the present assessment, most studies have focused on bird scaring lines.

### 3.1.1 Bird scaring lines

There have been a number of quantitative studies assessing the effectiveness of bird scaring (tori) lines across different fisheries and regions. Most of this research documented marked reductions in seabird captures when tori lines were used, compared with fishing without mitigation device or with other device types (e.g., see reviews by Bull 2007, Bull 2009, Løkkeborg 2011, Parker 2017).

Statistical analyses of observer data have documented marked reductions in seabird collisions with warp cables when bird scaring lines were deployed (Tamini et al. 2015, Tamini et al. 2023). These analyses revealed significantly lower numbers of seabird captures overall (recorded as collisions per hour) when using this mitigation device compared with trawl fishing without bird scaring lines. Significant differences were also evident for each of the main seabird species observed in the collisions, namely black-browed albatross *Thalassarche melanophris*, southern giant petrel *Macronectes giganteus*, northern giant petrel *Macronectes halli*, Cape petrel *Daption capense*, and white-chinned petrel *Procellaria aequinoctialis* (Tamini et al. 2015).

Studies quantifying reductions in seabird bycatch have reported declines between 70% and 95% in seabird mortalities across different trawl fisheries outside New Zealand waters (Melvin et al. 2011, Maree et al. 2014). An experimental trial comparing bird scaring lines with warp scarers and bird bafflers determined the former device type to offer the most effective mitigation (Sullivan et al. 2006).

In some of these studies, trawl fishing gear included a third cable, the sonde cable or net monitoring cable (e.g., see Melvin et al. 2011). Seabird mortality in trawl fisheries has been documented to be particularly high through contact with the sonde cable (Weimerskirch et al. 2000). For example, in Argentinean mid-water and bottom trawl fisheries, 85.7% of albatross and petrel bycatch was directly attributed to this gear component (Tamini et al. 2023). Nevertheless, the use of of bird scaring lines led to significant reductions in seabird bycatch in these fisheries, compared with fishing without the mitigation device. In New Zealand, the use of net sonde cables (or data transmission cables") has been prohibited since 1992, but a recent Fisheries New Zealand discussion paper proposes to revoke this prohibition (Fisheries New Zealand 2022).

Research from New Zealand is consistent with studies elsewhere, highlighting the efficacy of tori lines for preventing seabird bycatch in trawl fisheries (Middleton & Abraham 2007, Abraham & Thompson 2009). Experimental trials of different types of mitigation device in squid and hoki trawl fisheries indicated considerable reduction (80–95%) in the frequency of seabird interactions with fishing gear when tori lines were used (Middleton & Abraham 2007). Nevertheless, seabirds were also observed to interact with tori lines in these trials (and less so with bird bafflers and warp scarers), even though the severity of birds striking tori lines remained unknown. Similarly, an earlier analysis of fisheries observer data from primarily squid and also hoki fisheries reported considerably lower bird strike rates for the initial period following the introduction of tori lines between 2004–05 and 2006–07; however, there was some strike on bird scaring lines also (Abraham & Thompson 2009).

In addition, there have been at-sea trials of different specifications of tori lines, such as the material and configurations (Cleal et al. 2013). Results from the trials provided recommendations including the line attachment, and the size and weight of floats at the end of the lines (terminal objects), that were made available in a fact sheet.

Recognising their effectiveness, bird scaring lines are the only mitigation device type appraised as best practice for trawl fisheries by the Agreement on the Conservation of Albatrosses and Petrels (ACAP), with waste management and net cleaning reflecting other best-practice measures (Agreement on the Conservation of Albatrosses and Petrels 2023). Included in this advice by ACAP are recommended standards for the practical application of bird scaring lines, such as the maximum interval between streamer lines and terminal object drag weight.

### 3.1.2 Bird bafflers

Compared with tori lines, research into the effectiveness of bird bafflers had less distinct outcomes, although bird bafflers have been shown to reduce seabird captures (Parker 2017). Nevertheless, in a direct comparison that trialled bird bafflers, bird scaring lines and warp scarers, the former mitigation device (i.e., the Brady baffler) resulted in the smallest reduction in seabird mortality, although it was more effective than no mitigation (Sullivan et al. 2006). In addition, bird bafflers have undergone further development since these early studies.

Another comparison, an Australian study tested the efficacy of bafflers (and a water sprayer) on trawl vessels, revealing significant reductions (83.7%) in seabird interaction rates when compared with a warp deflector (Koopman et al. 2018). Based on this outcome, the Australian Fisheries Management Authority permitted the use of bird bafflers as part of the industry's requirements of seabird bycatch mitigation on trawl vessels.

In New Zealand trawl fisheries, statistical analysis of three years of fisheries observer data (2004–05 to 2006–07) indicated a lower strike rate when bird bafflers were used, but this reduction was not consistent nor significant across fishing years (Abraham & Thompson 2009). Nevertheless, although bird scaring lines had a markedly lower average strike rate than bird bafflers, there was a substantial further reduction when both mitigation device types were used in combination.

The New Zealand study of mitigation devices in squid and hoki trawler fisheries reported a significant reduction of 35–90% warp strike of large seabirds (defined as all albatrosses and giant petrels) compared with no mitigation; however, the reduction for small seabirds was not statistically significant (Middleton & Abraham 2007).

Overall, the efficacy of bird bafflers appears to be dependent on their design and configuration, and a number of trials have assessed different specifications and modifications, including in New Zealand fisheries (Cleal & Pierre 2012a). Nevertheless, there have been no clear standards or specifications of bird bafflers to date, and ACAP considered existing evidence insufficient to recommend bird bafflers as a mitigation measure in trawl fisheries (Agreement on the Conservation of Albatrosses and Petrels 2023).

### 3.1.3 Warp scarers

Similar to bird bafflers, limited research into the use of warp scarers documented some reductions in warp strike, but that they seem generally less effective than bird scaring lines (Bull 2007; and see review of trials in Parker 2017). For example, direct comparison of the three mitigation device types ranked warp scarers second after bird scaring lines, assessing them to be more effective for seabird bycatch mitigation than bird bafflers (Sullivan et al. 2006).

At the same time, at-sea trials of warp scarers (in comparison to warp deflectors) in Australia showed varied results of their efficacy, depending on the number of seabirds (i.e., "shy-type albatross" *Thalassarche*) and their behaviour around the stern of the vessel (Pierre et al. 2014). When bird numbers were high and birds were feeding aggressively, exploratory modelling suggested that warp scarers were effective in reducing warp interactions; however, they were less effective when birds were not aggressive during feeding or ended up submerged during interactions.

For New Zealand trawl fisheries, statistical modelling of observer data from the initial period of mitigation measures showed no significant reduction in warp strike rates associated with the use of warp scarers (Abraham & Thompson 2009). Subsequent at-sea trials of different mitigation devices indicated that warp scarers were effective in reducing warp strike compared with fishing without a mitigation device, but this reduction was more pronounced for large than small seabirds (Middleton & Abraham 2007).

As for bird bafflers, ACAP does not recommend warp scarers as a best-practice mitigation device, as there is insufficient evidence to support this recommendation (Agreement on the Conservation of Albatrosses and Petrels 2023).

### 3.2 Large-vessel trawl effort and observed capture rates

Considering trawl effort in relation to observed seabird captures across fisheries, a relatively small number of tows had records of seabird captures, which included net captures (Figure 1). Most of these records were associated with squid trawls, followed by hoki and middle-depth targets. A relatively small proportion of the former effort had capture records that were limited to warp captures (Figure 2).

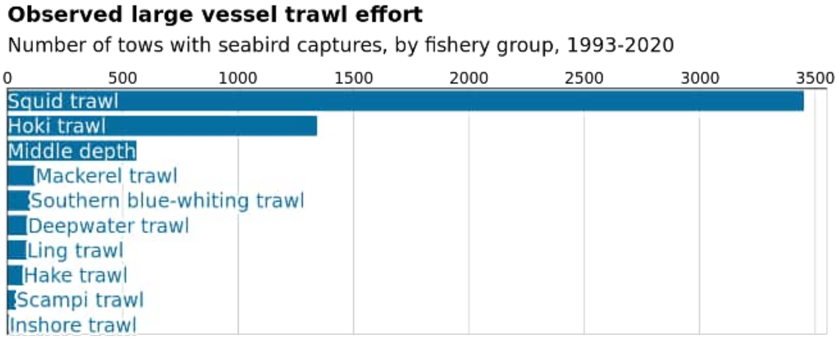


**Figure 1:** Observed fishing effort (tows) by large trawl vessels with seabird captures (all capture methods), for the period between 1992–93 and 2019–20, by fishery group.

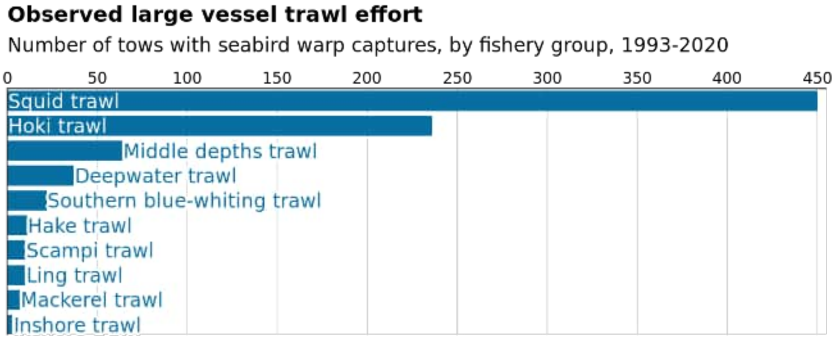


**Figure 2:** Observed fishing effort (tows) by large trawl vessels with seabird warp captures, for the period between 1992–93 and 2019–20, by fishery group.

Over the study period, the proportion of observed trawl effort by large vessels increased across a number of target fisheries since the mid- to late 2000s (Figure 3). This increase has resulted in a number of large-vessel trawl fisheries having close to 100% observer coverage since 2013, such as southern blue whiting and squid trawl. The only large-vessel trawl fishery with substantial effort and persistently low observer coverage over this period was the scampi target fishery.

There was considerable variability in observed seabird captures across large-vessel fisheries (Figure 4). For example, observed captures were consistently low in deepwater and inshore large-vessel trawl fisheries, but were comparatively high in squid and scampi trawl. In addition, there were marked changes in recorded captures over time, following increases in observer effort in early 2000.

For warp captures, most records were in large-vessel squid and hoki trawl fisheries, but there was considerable variation in captures over time (Figure 5). In some target fisheries, such as inshore, ling, middle-depth, and scampi trawl, there were distinct peaks among otherwise low warp captures over the study period.

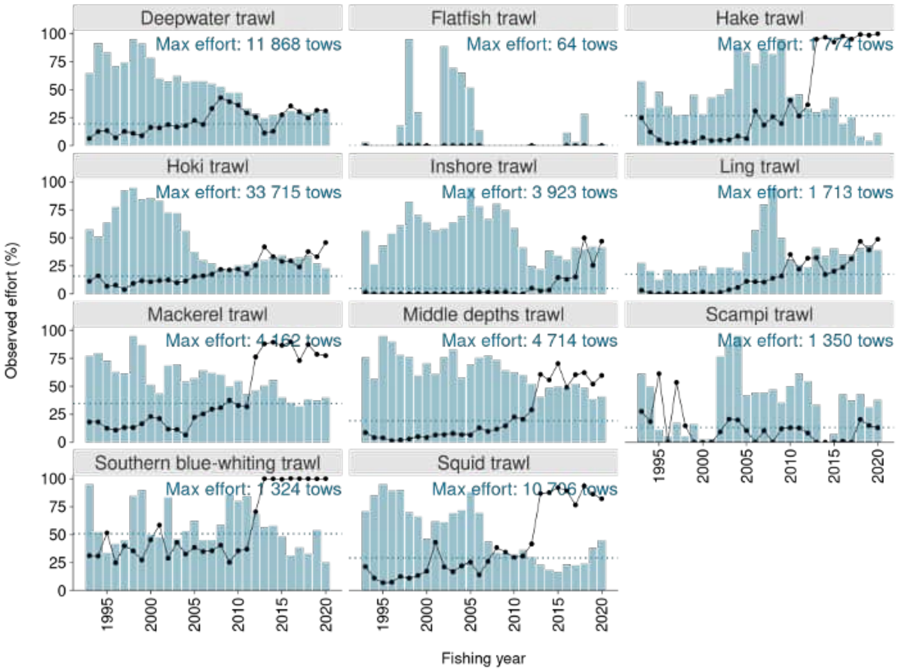


**Figure 3:** Observed (black dots) large vessel trawl effort (tows) as a percentage of total (bars) large vessel trawl effort, for the period between 1992–93 and 2019–20, by fishery group.

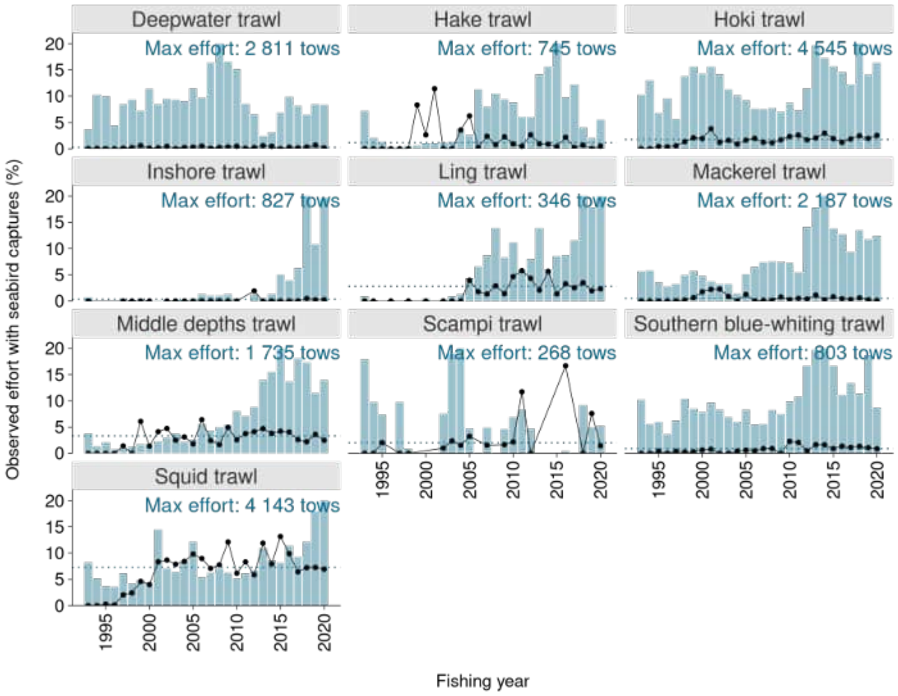


**Figure 4:** Observed (black dots) large vessel trawl effort (tows) with seabird captures from all capture methods, as a percentage of observed (bars) large vessel trawl effort, for the period between 1992–93 and 2019–20, by fishery group.

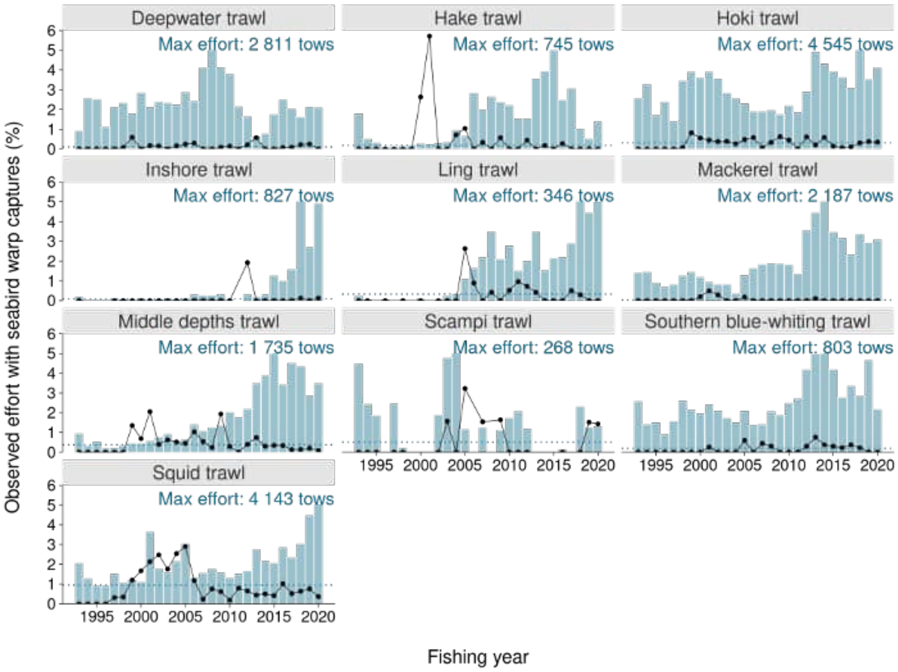


**Figure 5:** Observed (black dots) large vessel trawl effort (tows) with seabird warp captures, as a percentage of observed (bars) large vessel trawl effort, for the period between 1992–93 and 2019–20, by fishery group.

Considering warp captures in relation to observed effort, captures were particularly high prior to the introduction of mandatory mitigation measures in 2006 (Figure 6). This pattern was particularly evident in large-vessel squid trawl and to some extent in hoki trawl fisheries, which had sufficient effort to reveal discernible patterns.

Comparison of the number of observed warp captures and warp capture rates showed similar patterns (Figures 7 and 8). The observed number of warp captures was high in squid and hoki trawl fisheries, particularly before the introduction of mitigation measures. Similarly, observed warp capture rates were high in squid trawl in this earlier period, but also in middle-depth, hake, and scampi trawl.

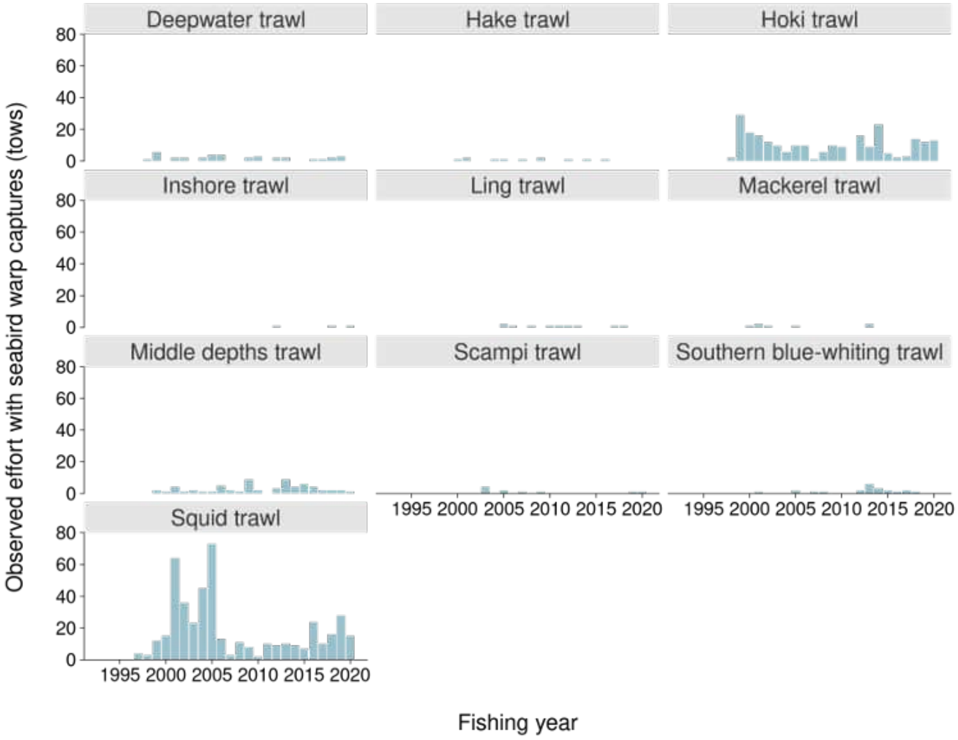


**Figure 6:** Observed large vessel trawl effort (tows) with seabird warp captures, for the period between 1992–93 and 2019–20, by fishery group.

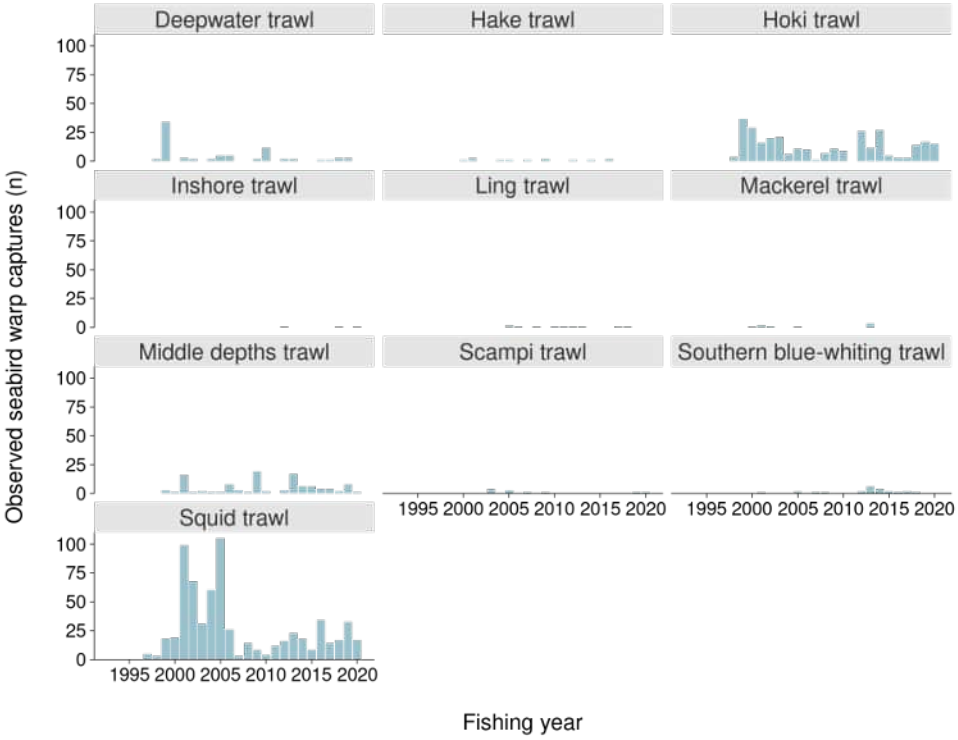


**Figure 7:** Observed large vessel trawl seabird warp captures, for the period between 1992–93 and 2019–20, by fishery group.

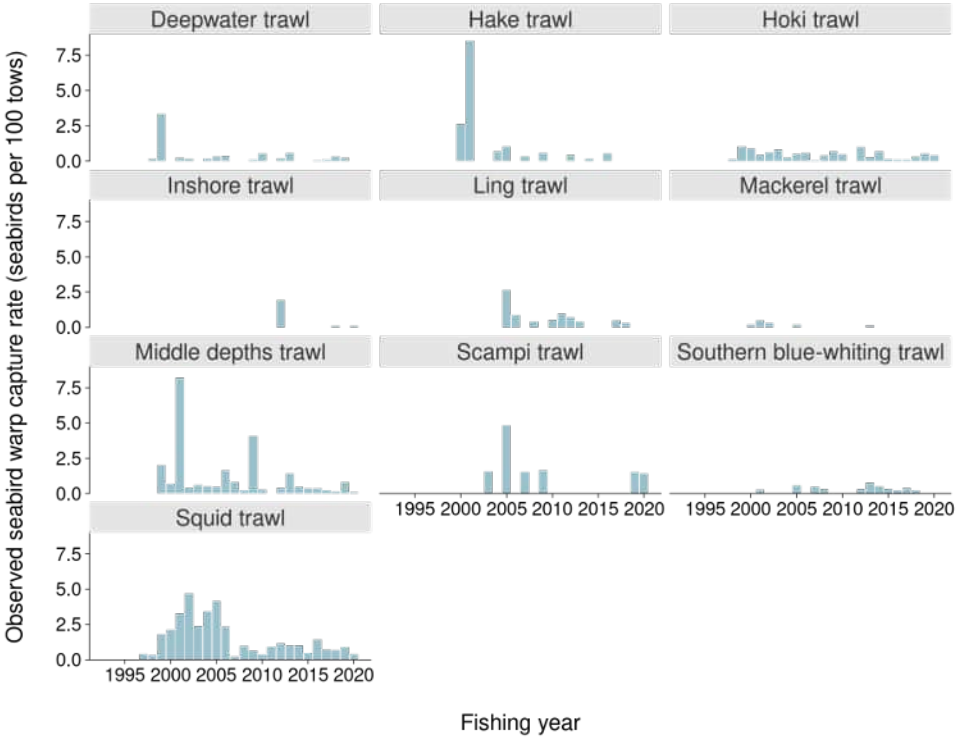


**Figure 8:** Observed large vessel trawl seabird warp capture rates, for the period between 1992–93 and 2019–20, by fishery group.

### 3.3 Configuration of mitigation devices

There were differences in the amount of information available in the database considering the configuration of devices (Tables 2 to 4). For tori lines, there was a total of 54 fields related to their configuration, but less than half of these fields contained values. In comparison, there were 14 fields for bird bafflers (generally all with values), and 21 fields for warp scarers (with most values filled in). Across all three types of mitigation device, there was a considerable number of different characteristics and unique configurations. This aspect was particularly prominent for tori lines, but also evident for the other two types of mitigation device.

Multiple mitigation devices may be used at the same time during a single fishing event, and their combination is stored in COD, in the field *mitigation_equipment* of table *x_fishing_event*. For example, a value of "B1T1T2" indicates the use of a bird baffler and two different tori lines. Each component of this value may be extracted and linked to the device characteristics for each fishing event using the trip number.

In the version of COD used in this project, the linking between the use of mitigation devices and the device characteristics was incomplete (Table 5). For example, there were 1187 fishing trips with some record relating to the use of tori lines, but only 837 trips had all records of the tori lines being deployed with a corresponding record of their characteristics. There were 227 trips with records of the tori lines characteristics, but without any record of them being used while fishing. Conversely, there were 120 trips with tori lines being used while fishing, but without data of their characteristics.

The linking was also incomplete for bird bafflers and warp scarers (Table 5). It is possible that some mitigation devices get characterised by observers when the devices are present on board the fishing vessels, though these devices may have not been used while fishing. Nevertheless, the presence of data confirming the use of devices while fishing but without corresponding information of their characteristics suggests that the latter were missed in the recording and management of this information.

For fishing events where the use of mitigation devices can be linked to the device characteristics, the configuration of the mitigation devices can potentially be related to the number of incidental captures of seabirds while fishing. These records were summarised separately for each mitigation device type, but without considering the potential simultaneous use of multiple device types (Table 6).

When calculating the "naive" capture rate, i.e., the ratio of the total number of seabird captures to the number of fishing events where the mitigation device type was used, the highest capture rate was when using tori lines at 6.4 birds per 100 fishing events. The capture rates for trawl fishing with bird bafflers and warp scarers was 3.4 birds per 100 fishing events and 2.3 birds per 100 fishing events, respectively. The lowest capture rate was for fishing events where none of these three mitigation device types were recorded, at 2 birds per 100 fishing events.

Nevertheless, the considerable number of unique configurations of mitigation devices deployed during fishing prevented the analysis of particular configurations in relation to seabird captures. For example, a total of 1 834 unique configurations of tori lines was recorded among the 45 938 fishing events observed using this mitigation device. Similarly, the simultaneous use of multiple mitigation types and the influence of other factors affecting seabird captures mean that further analysis through the development of multi-variate analysis of mitigation characteristics would be required in conjunction with a statistical model of effectiveness to ascertain which gear configurations are most effective at minimising the number of seabird warp-captures in large-vessel trawl fisheries.

**Table 2:** Description of the fields in the Centralised Observer Database (COD) related to the configuration of tori lines used on large (≥28 m length) trawl vessels. Shown are the number of fishing trips with some values, the number of unique values, and the percentage of values missing.

| Field name | Description | Trips with values | Unique values | Missing (%) |
|---|---|---|---|---|
| *line_diameter* | Diameter of the line used | 951 | 27 | 1.70 |
| *line_length* | Length of the line | 951 | 77 | 1.70 |
| *aerial_extent* | Aerial extent of tori line | 132 | 26 | 87.10 |
| *recovery_rope_yn* | Presence of tori line recovery rope | 176 | 2 | 83.10 |
| *reference_point* | Location of the point of attachment (trawl block, bait entry, other) | 737 | 5 | 23.20 |
| *reference_location* | Location of the reference point (port, startboard, central) | 718 | 3 | 25.20 |
| *distance_side* | Distance from the reference point to the attachment in the port/starboard direction | 764 | 49 | 19.40 |
| *side_code* | Whether the attachment point is to port or to starboard of the reference point | 959 | 3 | 0.00 |
| *distance_along* | Distance from the reference point to the attachment in the forward/aft direction | 735 | 39 | 22.30 |
| *along_code* | Whether the attachment point is to forward or aft of the reference point | 959 | 3 | 0.00 |
| *distance_vertical* | Distance from the reference point to the attachment point in the vertical direction | 752 | 37 | 20.40 |
| *vertical_code* | Attachment point is above or below the reference point | 959 | 3 | 0.00 |
| *attach1_tension_release_yn* | Presence of a tension release for the attachment point | 119 | 2 | 90.10 |
| *attach1_height* | Height of attachment point above water | 178 | 12 | 82.70 |
| *attach1_distance* | Lateral distance from centre of stern to attachment point | 179 | 32 | 82.50 |
| *attach1_port_stbd* | Port or Starboard lateral distance for attachment point measurement | 174 | 2 | 83.20 |
| *attach1_dist_stern* | Distance from stern to the attachment point | 176 | 26 | 83.00 |
| *attach1_adjustable_yn* | Whether attachment point is adjustable | 179 | 2 | 82.80 |
| *attach2_tension_release_yn* | Whether dual attachment point has a tension release | 110 | 1 | 90.00 |
| *attach2_height* | Height above water for dual attachment point | 9 | 6 | 99.20 |
| *attach2_distance* | Lateral distance from centre of stern to dual attach point | 7 | 6 | 99.50 |
| *attach2_port_stbd* | Port or Starboard lateral distance for dual attachment point measurement | 9 | 2 | 99.30 |
| *attach2_dist_join_stern* | Distance from join to stern | 1 | 1 | 99.90 |
| *attach2_dist_join_point* | Distance from join to attachment point | 2 | 2 | 99.80 |
| *attach2_streamer_join_yn* | Presence of streamers between second attachment point and join | 5 | 2 | 99.70 |
| *long_streamer_yn* | Presence of long streamers | 181 | 2 | 82.10 |
| *long_streamer_material* | All long streamer material types | 901 | 17 | 6.60 |
| *long_streamer_distance* | Maximum distance between any long streamers | 932 | 78 | 2.60 |
| *long_streamer_pair_single* | Whether streamers are single or paired | 173 | 2 | 83.10 |
| *long_streamer_number* | Number of long streamers, or pairs, along the entire tori line | 938 | 27 | 2.30 |
| *long_streamer_max_length* | Maximum length of any long streamer attached to the tori line | 935 | 99 | 2.50 |
| *long_streamer_min_length* | Minimum length of any long streamer attached to the tori line | 935 | 52 | 2.40 |
| *long_streamer_diameter* | Minimum diameter of any long streamer on the line | 916 | 25 | 5.40 |
| *long_streamer_colour_code* | All the streamer colours observed for long streamers | 932 | 66 | 3.20 |
| *long_streamer_dist_first* | Distance to first long streamer that reaches water | 164 | 21 | 84.00 |
| *long_streamer_aerial_yn* | Whether long streamers cover aerial extent | 165 | 2 | 83.80 |
| *long_streamer_touch_water_yn* | Whether all long streamers touch water surface | 0 | 0 | 100.00 |
| *long_streamer_height_water* | Maximum height of long streamers above the water surface | 0 | 0 | 100.00 |
| *long_streamer_num_touch_water* | Number of long streamers that touch water | 163 | 12 | 84.10 |
| *light_streamer_yn* | Presence of light streamers | 181 | 2 | 82.20 |
| *light_streamer_material* | All light streamer material types | 20 | 3 | 98.10 |
| *light_streamer_distance* | Distance between light streamers | 22 | 5 | 97.90 |
| *light_streamer_pair_single* | Whether light streamers are single or paired | 22 | 2 | 97.90 |
| *light_streamer_number* | Number of light streamers, or pairs, along the entire tori line | 22 | 10 | 97.90 |
| *light_streamer_max_length* | Maximum length of any light streamer attached to the tori line | 22 | 15 | 97.90 |
| *light_streamer_min_length* | Minimum length of any light streamer attached to the tori line | 22 | 8 | 98.00 |
| *light_streamer_diameter* | Minimum diameter of any light streamer on the line | 773 | 22 | 19.60 |
| *light_streamer_colour_code* | All the streamer colours observed for light streamers | 23 | 5 | 97.90 |
| *tow_object_yn* | Presence of towed object | 183 | 1 | 82.10 |
| *tow_object_code* | Type of towed object (inverted funnel, buoy, etc.) | 959 | 12 | 0.00 |
| *tow_object_size* | Size of the towed object | 885 | 75 | 7.70 |
| *minimum_branches* | Minimum number of branches on any streamer on the line | 754 | 8 | 21.00 |
| *maximum_branches* | Maximum number of branches on any streamer on the line | 756 | 9 | 21.10 |
| *comments* | Comments | 575 | 855 | 42.90 |

**Table 3:** Description of the fields in the Centralised Observer Database (COD) related to the configuration of bird bafflers used on large (≥28 m length) trawl vessels. Shown are the number of fishing trips with some values, the number of unique values, and the percentage of values missing.

| Field name | Description | Trips with values | Unique values | Missing (%) |
|---|---|---|---|---|
| *boom_position* | Boom position (port orstarboard and side or aft) | 1 618 | 4 | 0.00 |
| *boom_present* | Boom present or absent | 1 618 | 1 | 0.00 |
| *boom_location* | Distance to the appropriate reference point | 1 595 | 39 | 2.80 |
| *boom_angle* | Estimate of the angle of the boom from dead astern | 1 613 | 38 | 1.50 |
| *inner_dropper* | Distance from the edge of the vessel to the innermost dropper | 1 616 | 43 | 1.80 |
| *outer_dropper* | Total distance from the edge of the vessel to the outermost dropper | 1 613 | 71 | 1.90 |
| *droppers_number* | Number of droppers attached to the boom | 1 610 | 18 | 2.00 |
| *webbing_type* | Webbing Type connecting the droppers (rigid, flexible, or absent) | 1 564 | 4 | 5.10 |
| *max_spacing* | Maximum dropper spacing | 1 616 | 28 | 1.40 |
| *line_length* | Average dropper line length | 1 615 | 87 | 1.80 |
| *object_length* | Average dropper object length | 1 576 | 43 | 5.80 |
| *surface_gap* | Average gap between the bottom of a dropper object and the sea surface | 1 608 | 45 | 2.20 |
| *material_types* | All materials used to form the dropper lines and dropper object | 1 584 | 198 | 4.30 |
| *material_colours* | Colours on dropper | 1 580 | 159 | 5.10 |

**Table 4:** Description of the fields in the Centralised Observer Database (COD) related to the configuration of warp scarers used on large (≥28 m length) trawl vessels. Shown are the number of fishing trips with some values, the number of unique values, and the percentage of values missing.

| Field name | Description | Trips with values | Unique values | Missing (%) |
|---|---|---|---|---|
| *attachment_point* | Location of the point of attachment (port, starboard, central, or other) | 18 | 3 | 2.80 |
| *mainline_diameter* | Diameter of the mainline used | 18 | 11 | 2.80 |
| *tow_object* | Type of towed object | 16 | 6 | 19.40 |
| *object_weight* | Weight of the towed object | 18 | 15 | 5.60 |
| *connector_type* | Type of connector (clip, shackle, or hook) | 16 | 3 | 8.30 |
| *connector_number* | Number of connectors holding main line to warp | 16 | 5 | 11.10 |
| *streamer_number* | Number of streamers | 14 | 7 | 27.80 |
| *streamer_max_gap* | Largest gap from one streamer to the next | 12 | 8 | 30.60 |
| *streamer_min_branches* | Minimum number of branches on any streamer on the line | 13 | 3 | 27.80 |
| *streamer_max_branches* | Maximum number of branches on any streamer on the line | 11 | 2 | 33.30 |
| *streamer_min_length* | Minimum length of any branch of any streamer on the line | 13 | 10 | 27.80 |
| *streamer_max_length* | Maximum length of any branch of any streamer on the line | 12 | 12 | 30.60 |
| *streamer_min_dia* | Minimum diameter of any branch of any streamer on the line | 12 | 7 | 30.60 |
| *streamer_max_dia* | Maximum diameter of any branch of any streamer on the line | 11 | 7 | 36.10 |
| *extent_distance* | Estimate of the extent (distance) or coverage of the warp scarer | 17 | 14 | 8.30 |
| *material_max_gap* | Maximum gap visible in materials | 14 | 12 | 25.00 |
| *mainline_visible_min_lgth* | Minimum length of the main line visible material | 16 | 14 | 13.90 |
| *mainline_visible_max_lgth* | Maximum length of the main line visible material | 16 | 16 | 16.70 |
| *colours* | All the different streamer colours observed | 19 | 15 | 0.00 |
| *materials* | All the different streamer materials observed | 17 | 10 | 5.60 |
| *comments* | Comments | 16 | 22 | 25.00 |

**Table 5:** Summary of the linking between data on the use and characteristics of mitigation devices on large (≥28 m length) trawl vessels recorded by fisheries observers. Data are shown by mitigation device type, including the number of fishing trips.

| Mitigation | Recorded | Characterised | No. trips |
|---|---|---|---|
| Tori lines | Yes | Yes | 837 |
| | No | Yes | 227 |
| | Yes | No | 120 |
| | No | No | 3 |
| Bird bafflers | Yes | Yes | 1 375 |
| | Yes | No | 313 |
| | No | Yes | 30 |
| | No | No | 2 |
| Warp scarers | Yes | No | 18 |
| | Yes | Yes | 18 |
| | No | Yes | 12 |

**Table 6:** Summary of data in the Centralised Observer Database with information of the configuration of mitigation devices that could be related to the number of incidental captures of seabirds in large-vessel (≥28 m length) trawl fisheries. For each type of mitigation device, shown are the number of trips and of fishing events with recorded use the mitigation device, the number of unique combinations of device characteristics, the observed number of seabird captures, and the capture rate (number of captures per 100 fishing events). Number of trips, of fishing events, and of seabird captures were not independent across mitigation device types, with some fishing events using multiple device types simultaneously.

| Mitigation | Trips | Fishing events | Unique configurations | Seabird captures | Capture rate |
|---|---|---|---|---|---|
| Tori lines | 958 | 45 938 | 1 834 | 2 957 | 6.44 |
| Bird bafflers | 1 612 | 124 628 | 3 557 | 4 221 | 3.39 |
| Warp scarers | 19 | 833 | 36 | 19 | 2.28 |
| None | 413 | 11 915 | | 241 | 2.02 |

## 3.4 Relative effectiveness of warp mitigation gear

Mitigation device use has been consistently recorded across large-vessel trawl fisheries since 2008, following the introduction of mandatory measures in 2007 (Table 7). Nevertheless, missing records of the use of mitigation devices included empty fields for warp mitigation gear type ("Not recorded") and missing information recorded as "None" by observers in this field, leading to the lack of these data in COD. Following the mandatory nature of the use of mitigation devices after 2007, missing information of warp strike mitigation devices continued to be evident in the observer records over time across the large-vessel trawl fleet (Figure 9). These records were excluded from the present analysis.

Comparing observer records across different mitigation device types and combinations, bird bafflers were the most prevalent mitigation gear used each fishing year (Figure 10). In addition, there was a marked increase in the number of tows that used bird bafflers over time (i.e., since 2008). Bird bafflers in combination with tori lines were also used on a comparatively high number of tows over this period, followed by the use of tori lines only. Warp scarers and other combinations of mitigation gear were only used on a small number of tows.

The use of bird bafflers on a relatively high number of large-vessel trawl fishing trips was consistent over time, particularly since 2013 (Figure 11). This pattern was similar for the combination of bird bafflers and tori lines, with a considerable number of vessels using this mitigation gear combination (Figure 12). For the use of tori lines, there was an increase in the number of fishing trips with this mitigation gear in the middle of the reporting period, but there was a concomitant reduction of vessels using this combination (Figure 13).

There were only limited observer records of the use of warp scarers (Figure 14), preventing inclusion of these data in the modelling part of this study.

**Table 7:** Use of warp mitigation devices as recorded by fisheries observers in large-vessel (≥28 m length) trawl fisheries for the period between 1992–93 and 2019–20. Shown are the number of tows by warp strike mitigation gear and by fishing year. Records shown as “Not recorded” indicate that the warp mitigation gear type fields were empty in the observer data form; “None” indicated lack of information of mitigation gear use recorded by observers.

| Fishing year | Not recorded | None | Baffler | Tori | Scarer | Baffler & tori | Bafflers & scarer | Tori & scarer | Baffler & tori & scarer |
|---|---|---|---|---|---|---|---|---|---|
| 1993 | 6 429 | | | | | | | | |
| 1994 | 6 657 | | | | | | | | |
| 1995 | 4 676 | | | | | | | | |
| 1996 | 4 052 | | | | | | | | |
| 1997 | 4 534 | | | | | | | | |
| 1998 | 6 418 | | | | | | | | |
| 1999 | 6 695 | | | | | | | | |
| 2000 | 6 779 | | | | | | | | |
| 2001 | 8 753 | | | | | | | | |
| 2002 | 7 103 | | | | | | | | |
| 2003 | 6 453 | | | | | | | | |
| 2004 | 6 364 | | | | | | | | |
| 2005 | 7 587 | | | | | | | | |
| 2006 | 6 183 | | | | | | | | |
| 2007 | 4 817 | 377 | 993 | 870 | 55 | 133 | | | |
| 2008 | 5 | 697 | 4 738 | 1 941 | 207 | 696 | | 12 | |
| 2009 | | 277 | 4 447 | 1 803 | 259 | 605 | | 15 | |
| 2010 | | 152 | 4 878 | 1 458 | 12 | 1 176 | | | |
| 2011 | | 189 | 4 043 | 904 | | 1 077 | | | |
| 2012 | 245 | 104 | 5 874 | 803 | | 1 354 | | | |
| 2013 | | 127 | 7 265 | 1 350 | 1 | 3 073 | 1 | | |
| 2014 | 37 | 250 | 7 281 | 959 | | 2 695 | | | |
| 2015 | 29 | 134 | 8 178 | 929 | | 1 993 | | | |
| 2016 | | 127 | 8 436 | 574 | | 1 619 | | | |
| 2017 | 1 | 286 | 6 508 | 477 | | 2 628 | | | |
| 2018 | 1 | 225 | 8 595 | 92 | | 3 866 | 58 | | |
| 2019 | | 124 | 8 211 | 4 | | 3 679 | | | 1 |
| 2020 | | 137 | 8 720 | 25 | | 4 406 | 90 | | 2 |

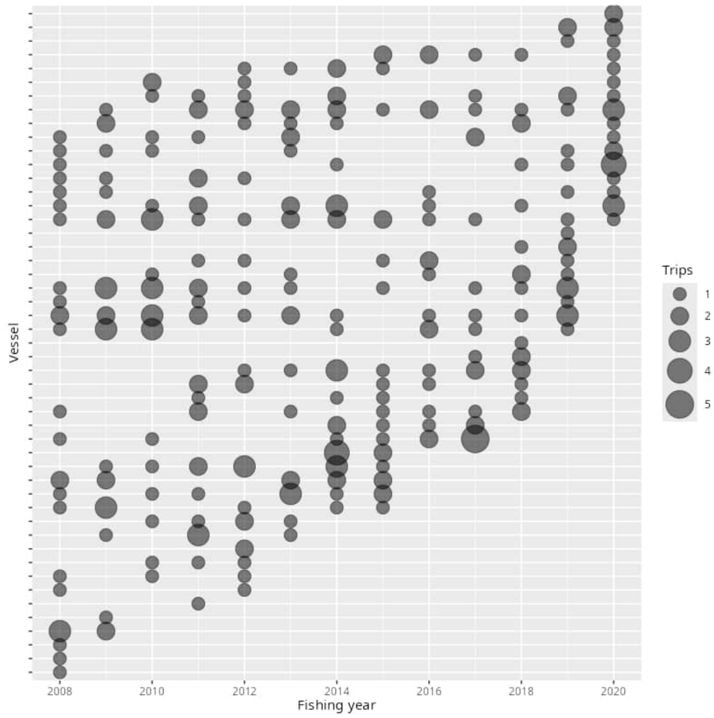


**Figure 9:** Number of large-vessel (≥28 m length) trawl fishing trips without data of the use of warp strike mitigation gear by vessel and fishing year, for the period between 2008–09 and 2019–20. These data were either not recorded or recorded as "none" in the mitigation device field by fisheries observers.

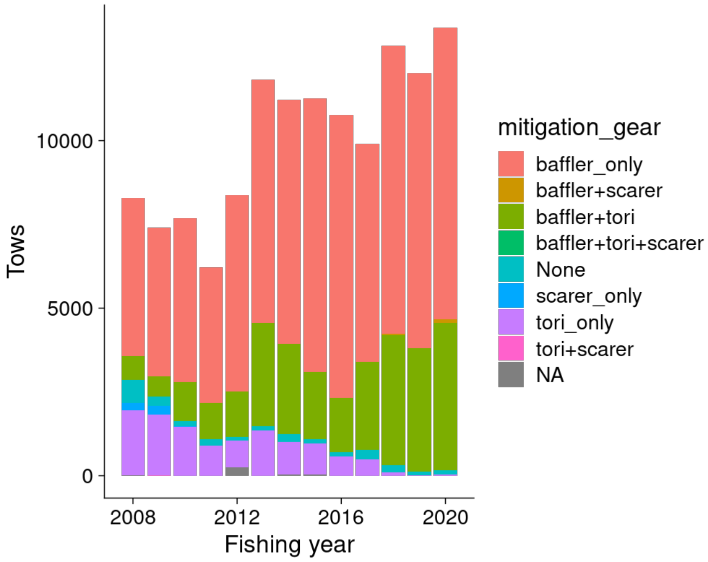


**Figure 10:** Number of tows with different warp strike mitigation gear as recorded by fisheries observer in large-vessel (≥28 m length) trawl fisheries for the period between 2008–09 and 2019–20. NA, no data available of the gear type used.

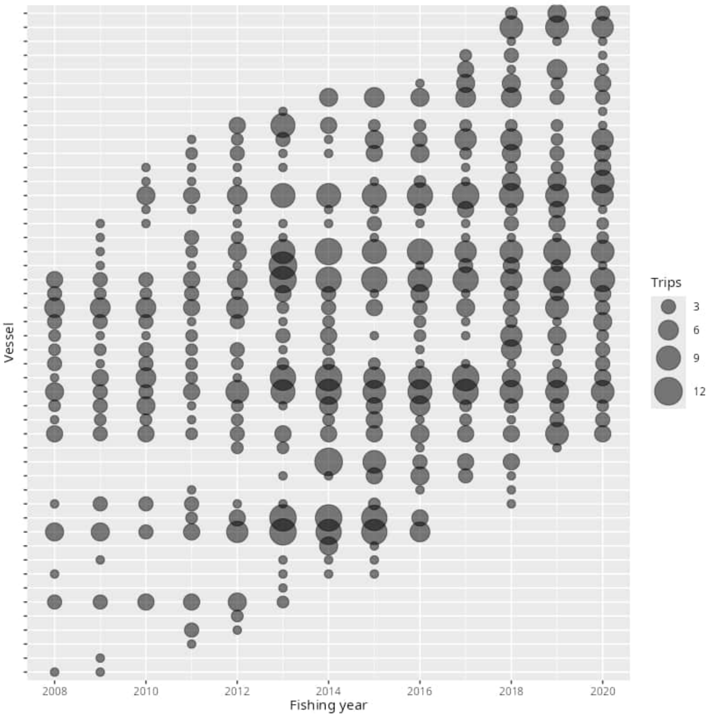


**Figure 11:** Number of fishing trips by large (≥28 m length) trawl vessels with warp strike mitigation use recorded as bird bafflers. Records are shown by vessel and fishing year, for the period between 2008–09 and 2019–20.

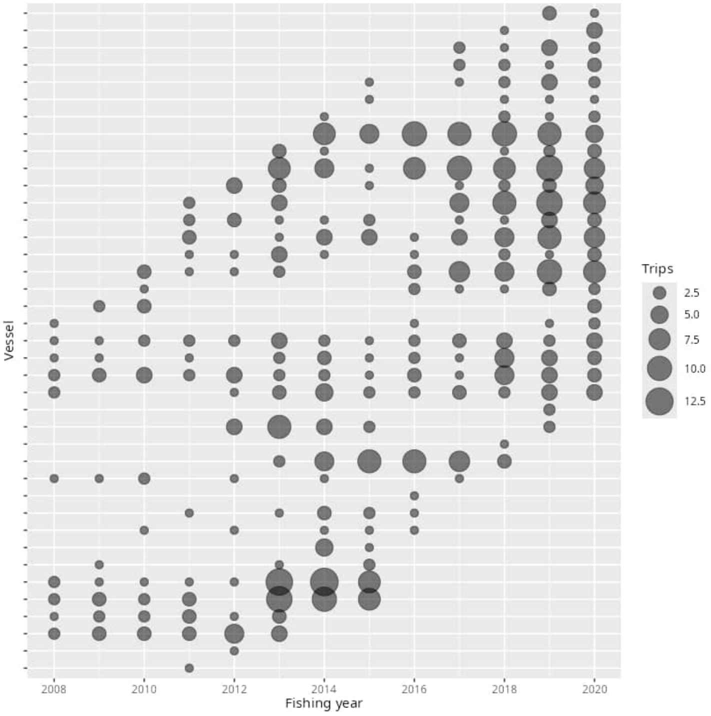


**Figure 12:** Number of fishing trips by large (≥28 m length) trawl vessels with warp strike mitigation use recorded as a combination of bird bafflers and tori lines. Records are shown by vessel and fishing year, for the period between 2008–09 and 2019–20.

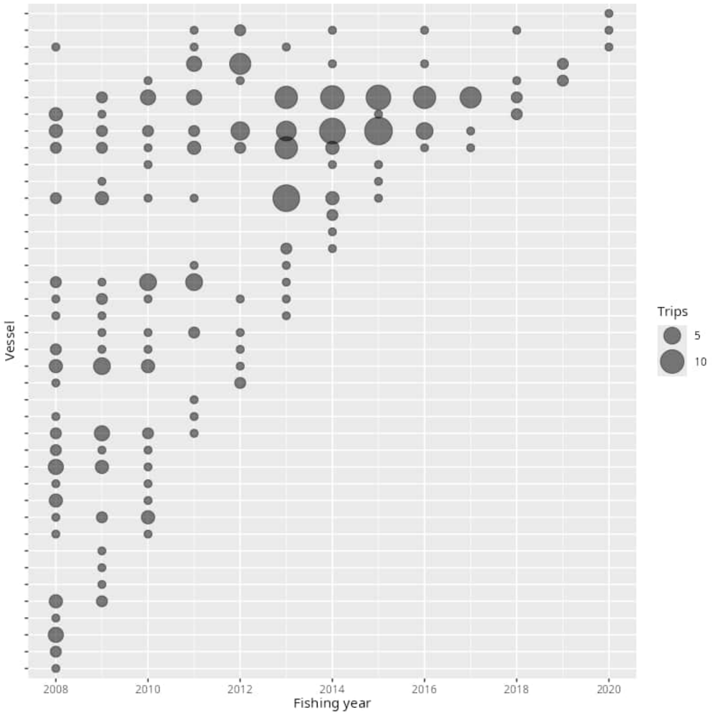


**Figure 13:** Number of fishing trips by large (≥28 m length) trawl vessels with warp strike mitigation use recorded as tori lines. Records are shown by vessel and fishing year, for the period between 2008–09 and 2019–20.

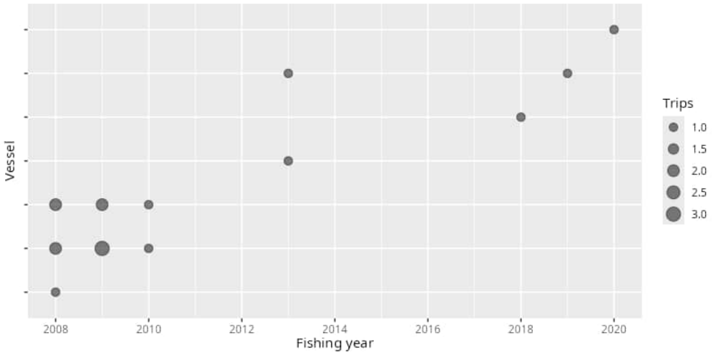


**Figure 14:** Number of fishing trips by large (≥28 m length) trawl vessels with warp strike mitigation use recorded as warp scarers. Records are shown by vessel and fishing year, for the period between 2008–09 and 2019–20.

Assessing the performance of the different capture rate models, models 2 to 8 performed well, with SRF and MSRF values close to 1 for all variables, indicating convergence. In contrast, model 1 did not converge (see Appendix A, Figures A-1 and A-2 for model selection; Appendix B, Figures B-1 to B-3 for model diagnostics).

The best fit to the data was by models 8 and 9 (Figure A-1). These models included random effects for year and vessel, whereas the other models did not include these random effects. Distribution and trace plots of the estimated parameters showed reasonable mixing of MCMC chains for Model 8, and confirmed convergence (Figure B-1). Posterior predictive assessments for this model indicated that the model fit the data well for each of the mitigation gear categories (Figure B-3).

The best performing models (in order: models 8, 9, 7, and 6) had consistent results, and all models included an effect for vessel and for fishing year (Figure A-2). Compared with the use of bird bafflers, the model estimates indicated that tori lines were more effective (Figure 15). The combination of bafflers and tori lines was slightly less effective than the use of bird bafflers only; however, this result was inconsistent among models.

Model estimates and 95% credible intervals for the levels of mitigation gear by year suggested that the effectiveness of bird bafflers has improved, especially after 2015 (Figure 16). The effectiveness of tori lines (and tori lines used in combination with bird bafflers) was less variable than the effectiveness of bird bafflers only over time. Estimates and 95% credible intervals from Model 9 for the levels of mitigation gear by vessel suggested the effectiveness of tori lines was relatively consistent among vessels, whereas the effectiveness of bird bafflers was highly variable (Figure 17).

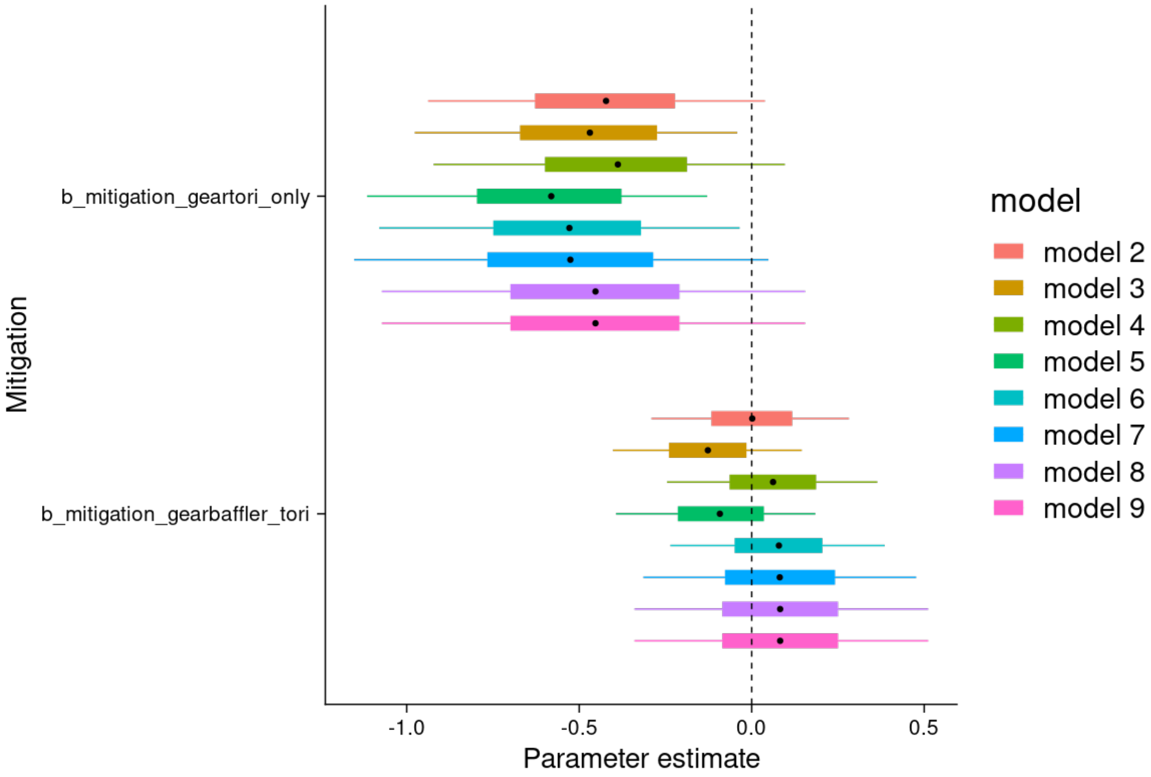


**Figure 15:** Model estimates and 95% credible intervals by model for the two types of warp strike mitigation gear, tori lines and the combination of bird bafflers and tori lines. For the modelling, bird bafflers only were the reference level at 0. A parameter estimate of less than 0 indicates a capture rate less than that for bird bafflers only, with the opposite indication for a parameter estimate great than 0.

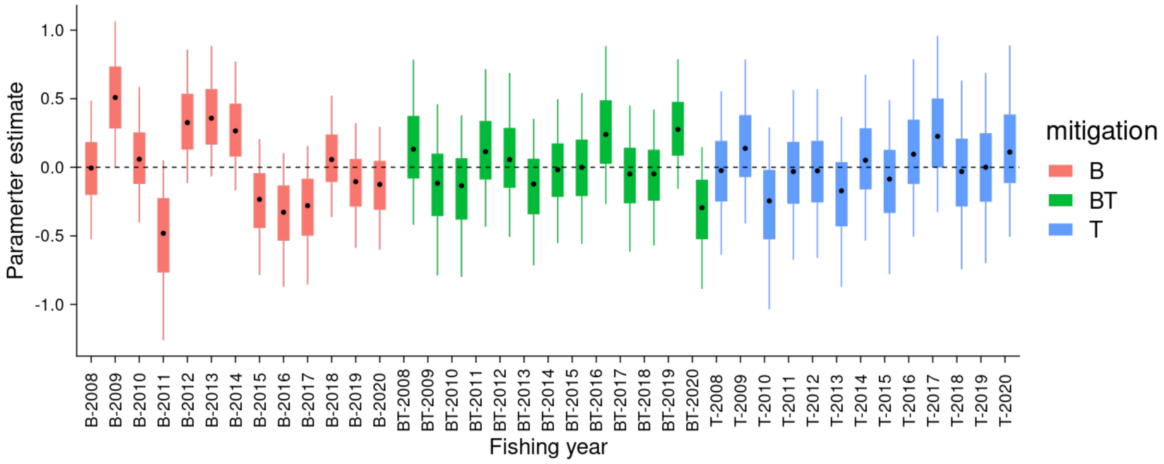


**Figure 16:** Model estimates and 95% credible intervals (Model 9) for the levels of the interaction effect combining fishing year and warp strike mitigation gear. Mitigation gear was: B, bird bafflers; BT, bird baffles and tori lines; T, tori lines. Reference level at 0 shows the average effect of each mitigation gear.

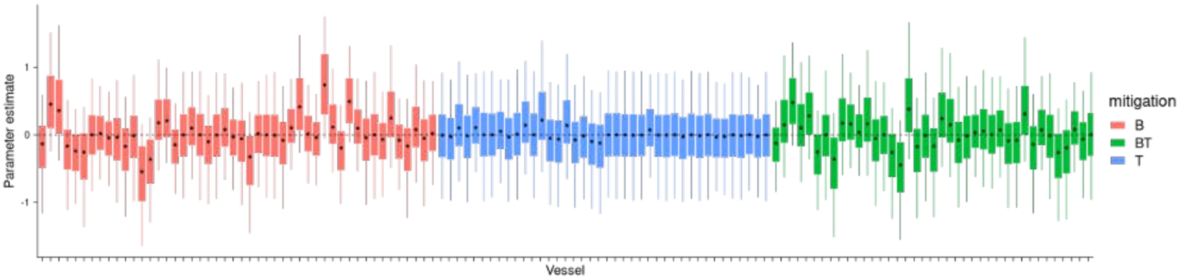


**Figure 17:** Model estimates and 95% credible intervals (Model 9) for the levels of the interaction effect combining vessel and warp strike mitigation gear. Mitigation gear was: B, bird bafflers; BT, bird baffles and tori lines; T, tori lines. Reference level at 0 shows the average effect of each mitigation gear.

## 4. DISCUSSION

The capture rate of seabirds depends on a number of factors, including the bird species, fishing location, target species, time of day, season, type of fishery, and waste management (Abraham & Richard 2019, Edwards & Dunn 2021, Pierre et al. 2012). Within this context, the current study aimed to elucidate the use of different mitigation gear in large-vessel trawl fisheries, and its potential influence on seabird captures (i.e., warp strike). Findings revealed a difference in effectiveness between the use of bird bafflers and tori lines. Nevertheless, trends were variable by year, particularly for the use of bird bafflers. The effectiveness of bird scaring or tori lines was estimated to be higher relative to bird bafflers alone, and their effect was also more consistent. This finding corresponds with other studies of seabird bycatch mitigation, which compared seabird captures across different mitigation devices in New Zealand trawl fisheries (Middleton & Abraham 2007, Abraham & Thompson 2009).

Nevertheless, the effectiveness of bird bafflers improved over time, suggesting potential improvements in their deployment in large-vessel trawl fisheries. Research in New Zealand has focused on updates and improvements to the design and at-sea trials of this mitigation device (Cleal & Pierre 2012a). Determining a potential relationship between these improvements and seabird capture rates requires further analysis, which could be part of a follow-up, in-depth analysis of the configuration of bird bafflers (and other mitigation devices).

This type of detailed analysis may focus on an overview of baffler configurations across large-vessel trawl fisheries, including the identification of updated and novel baffler configurations used. This analysis may also incorporate other sources of information, such as operational documents that may contain additional detail about the mitigation devices.

There was no evidence to suggest increased efficacy of the combination of tori lines and bird bafflers compared with the use of bird bafflers alone. This result is in contrast to earlier research, which showed reductions in seabird captures associated with the use of this combination of mitigation gear (Abraham & Thompson 2009). The current finding may be due to temporal aspects confounding improvements in the use of bird baffler use, and the use of bird scaring lines in combination with bird bafflers. Use of the latter combination increased markedly at the time when the efficacy of bird bafflers also increased. This finding may be related to the use of multiple mitigation device types during "high risk" periods, when high numbers of birds are foraging around vessels (e.g., during the peak squid trawl season). Further analysis may focus on elucidating this aspect including temporal patterns.

In contrast to the combination of tori lines and bird bafflers, the use of only bird scaring lines as a mitigation device declined to low level after 2017. For this reason, the documented difference between bird bafflers and tori lines as sole mitigation devices was largely based on data from a period when bird bafflers were estimated to be less effective. In comparison, the difference in efficacy between bird bafflers only and their combination with bird scaring lines was estimated from a period of overlap, dominated by years of data when bird bafflers were more effective. This potentially confounding factor may potentially be addressed in additional, more detailed data analyses.

Due to the lack of reporting of mitigation measures prior to their mandatory introduction, it was not possible to model the effectiveness of mitigation gear following its introduction. For this reason, the estimates here were relative between mitigation gear types. The considerable number of characteristics of mitigation devices and of unique configurations, the simultaneous use of multiple mitigation types, and the presence of other factors affecting seabird captures make it challenging to assess and derive an optimal configuration of mitigation gear. The preliminary analysis of gear characteristics suggested that this limitation is complex, preventing the inclusion of gear configurations in the modelling here. Using multivariate analysis, it may be possible to characterise "clusters" of gear configurations. These clusters would provide a potential way to incorporate a condensed form of these gear tables into models of gear efficiency. Although it is uncertain whether there will be sufficient statistical power to distinguish the effectiveness of different gear configurations given the relative rarity of warp strikes, this type of analysis is worth exploring in future efforts aimed at determining the efficacy of warp strike mitigation devices.

While the present study provided an initial exploration of the use of mitigation devices based on the three main device types, further analysis may focus on details of gear configurations, while also incorporating information from other sources. The latter may include operational documents and observer diaries that may provide further information of the use of mitigation devices and their configuration.

Further research may also include experimental studies that focus on the effectiveness of mitigation device types and their configurations. While an experimental approach may be able to assess the effectiveness of mitigation devices, these trials require considerable resources and would be limited to varying only some of the parameters of mitigation configurations. In contrast, existing data on seabird captures, fishing practices, and mitigation configurations are available and can be used to derive a more detailed estimate of the effectiveness of mitigation gear. These analyses are complex due to confounding factors and the lack of independent variations in the configuration parameters that prevent the analysis of each parameter independently. Nevertheless, a more in-depth analysis of these data is likely to increase the understanding of the effectiveness of mitigation devices.

Recommendations from the present data exploration and analysis include:

- Exploration of different techniques to analyse the diversity of gear configuration, including clustering algorithms and dimensionality reduction. These techniques allow the grouping of mitigation device configurations into consistent sets. This approach addresses the limitation that configuration parameters cannot be analysed independently, and could be used to facilitate the comparison of capture rates between parameters.
- Use of these groupings to assess differences in bycatch rates, while taking into account the relative abundance of species. For example, seabird counts at the back of fishing vessels are carried out regularly, and these data could be linked to fishing events to control for the abundance of seabirds and normalise capture rates.
- Analysing the influence of waste management, which has varied over time and been shown to impact the abundance of birds around vessels (Pierre et al. 2012).

In addition, the collection of data on-board fishing vessels by fishery observers could be improved by:

- Ensuring that both the use of mitigation devices and their configuration are recorded in a consistent way.
- Clearly distinguishing between the lack of device use and the lack of a record of device use.
- Conduct a rapid assessment of the abundance and activity of seabirds around the fishing gear for inclusion in the analysis.
- Consistent recording of the discharge of fishing waste.
- Use of onboard cameras to record factors that facilitate an in-depth analysis of mitigation device use, such as the abundance of seabirds, the use of mitigation, and waste discharge.

## 5. ACKNOWLEDGEMENTS

This study was funded by Department of Conservation under project MIT2022-05.

We are grateful to the fisheries observers who collected the data that formed the basis for the current study of mitigation devices in large-vessel trawl fisheries.

## 6. REFERENCES

Abraham, E. R. & Kennedy, A. (2008). Seabird warp strike in the southern squid trawl fishery, 2004–05. *New Zealand Aquatic Environment and Biodiversity Report No. 16*. 39 p.

Abraham, E. R.; Pierre, J. P.; Middleton, D. A. J.; Cleal, J.; Walker, N. A., & Waugh, S. M. (2009). Effectiveness of fish waste management strategies in reducing seabird attendance at a trawl vessel. *Fisheries Research*, *95*(2-3), 210–219. doi:10.1016/j.fishres.2008.08.014

Abraham, E. R. & Richard, Y. (2019). Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2015–16. *New Zealand Aquatic Environment and Biodiversity Report No. 211*. 99 p.

Abraham, E. R. & Richard, Y. (2020). Estimated captures of seabirds in New Zealand trawl and longline fisheries, to 2017–18. *New Zealand Aquatic Environment and Biodiversity Report No. 249*. 86 p.

Abraham, E. R. & Thompson, F. N. (2009). Warp strike in New Zealand trawl fisheries, 2004–05 to 2006–07. *New Zealand Aquatic Environment and Biodiversity Report No. 33*. 22 p.

Agreement on the Conservation of Albatrosses and Petrels (2023). *ACAP review of mitigation measures and best practice advice for reducing the impact of pelagic and demersal trawl fisheries on seabirds. reviewed at the thirteenth meeting of the advisory committee. edinburgh, united kingdom. 22–26 may 2023.* Agreement on the Conservation of Albatrosses and Petrels, Hobart.

Bull, L. S. (2007). Reducing seabird bycatch in longline, trawl and gillnet fisheries. *Fish and Fisheries*, *8*.

Bull, L. S. (2009). New mitigation measures reducing seabird by-catch in trawl fisheries. *Fish and Fisheries*, *10*, 408–427.

Bürkner, P.-C. (2018). Advanced Bayesian multilevel modeling with the r package brms. *The R Journal*, *10*(1), 395–411. doi:10.32614/RJ-2018-017

Clay, T. A.; Small, C.; Tuck, G. N.; Pardo, D.; Carneiro, A. P. B.; Wood, A. G.; Croxall, J. P.; Crossin, G. T., & Phillips, R. A. (2019). A comprehensive large-scale assessment of fisheries bycatch risk to threatened seabird populations. *Journal of Applied Ecology*, *56*, 1–12.

Cleal, J. & Pierre, J. P. (2012a). *Development of bird baffler designs for offshore trawl vessels*. Wellington, New Zealand: Department of Conservation. Conservation Services Programme Project MIT2013/06. 23 p

Cleal, J. & Pierre, J. P. (2012b). *Seabird scaring devices in use on trawlers ≥ 28 m in length operating in New Zealand fisheries*. Wellington, New Zealand: Department of Conservation.

Cleal, J.; Pierre, J. P., & Clement, G. (2013). *Warp strike mitigation devices in use on trawlers ≥ 28 m in length operating in New Zealand fisheries*. 42 p. Wellington, New Zealand: Department of Conservation. Retrieved from http://www.doc.govt.nz/publications/conservation/marine-and-coastal/conservation-services-programme/csp-reports/warp-strike-mitigation-devices/

Dias, M.; Martin, R.; Pearmain, E.; Burfield, I.; Small, C.; Phillips, R.; Yates, O.; Lascelles, B.; Borboroglu, P., & Croxall, J. (2019). Threats to seabirds: A global assessment. *Biological Conservation*, *237*, 525–537.

Edwards, C. T. T. & Dunn, A. (2021). Assessment of risk factors for seabird net captures in selected sub-Antarctic trawl fisheries. *New Zealand Aquatic Environment and Biodiversity Report No. 266*. 51 p. Retrieved from https://www.mpi.govt.nz/dmsdocument/46594-AEBR-266-Assessment-of-risk-factors-for-seabird-net-captures-in-selected-sub-Antarctic-trawl-fisheries

Favero, M.; Blanco, G.; García, G.; Copello, S.; Pon, J. P. S.; Frere, E.; Quintana, F.; Yorio, P.; Rabuffetti, F.; Cañete, G. G., et al. (2011). Seabird mortality associated with ice trawlers in the Patagonian shelf: effect of discards on the occurrence of interactions with fishing gear. *Animal Conservation*, *14*(2), 131–139.

Favero, M. & Seco Pon, J. P. (2014). Challenges in seabird by-catch mitigation. *Animal Conservation*, *17*(6), 532–533.

Fisheries New Zealand (2022). *Proposed technical amendments to fisheries regulations*. Fisheries New Zealand Discussion Paper No. 2022/01. Wellington: Fisheries New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/49321-Proposed-technical-amendments-to-fisheries-regulations-Discussion-document

Fisheries New Zealand and Department of Conservation (2020). *National Plan of Action – Seabirds 2020. Reducing the incidental mortality of seabirds in fisheries*. Wellington: Fisheries New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/40652-National-Plan-Of-Action-Seabirds-2020-Report

Goad, D. & Williamson, J. (2015). *Improving and documenting seabird bycatch mitigation practices in the North Eastern New Zealand longline fishery*. Unpublished report prepared by Vita Maris for the New Zealand Department of Conservation, Wellington. Retrieved from http://www.doc.govt.nz/our-work/conservation-services-programme/csp-reports/2014-15/improving-and-documenting-seabird-bycatch-mitigation-practices-in-the-north-eastern-new-zealand-longline-fishery

Koopman, M.; Boag, S.; Tuck, G. N.; Hudson, R.; Knuckey, I., & Alderman, R. (2018). Industry-based development of effective new seabird mitigation devices in the southern Australian trawl fisheries. *Endangered Species Research*, *36*, 197–211.

Kuepfer, A.; Sherley, R. B.; Brickle, P.; Arkhipkin, A., & Votier, S. C. (2022). Strategic discarding reduces seabird numbers and contact rates with trawl fishery gears in the Southwest Atlantic. *Biological Conservation*, *266*, 109462.

Løkkeborg, S. (2011). Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries - efficiency and practical applicability. *Marine Ecology Progress Series*, *435*, 285–303.

Maree, B. A.; Wanless, R. M.; Fairweather, T.; Sullivan, B., & Yates, O. (2014). Significant reductions in mortality of threatened seabirds in a South African trawl fishery. *Animal Conservation*, *17*(6), 520–529.

Melvin, E. F.; Dietrich, K. S.; Fitzgerald, S., & Cardoso, T. (2011). Reducing seabird strikes with trawl cables in the pollock catcher-processor fleet in the eastern Bering Sea. *Polar Biology*, *34*.

Melvin, E. F.; Guy, T. J., & Read, L. B. (2013). Reducing seabird bycatch in the South African joint venture tuna fishery using bird-scaring lines, branch line weighting and nighttime setting of hooks. *Fisheries Research*, *147*.

Middleton, D. A. J. & Abraham, E. R. (2007). *The efficacy of warp strike mitigation devices: Trials in the 2006 squid fishery*. Final Research Report for research project IPA2006/02. (Unpublished report held by Ministry for Primary Industries, Wellington). Retrieved from http://fs.fish.govt.nz/Page.aspx?pk=113&dk=22910

New Zealand Government (2010). Fisheries (commercial fishing) regulations 2001. seabird scaring devices circular 2010 (no. F517). *New Zealand Gazette*, *29*, 763–767.

Parker, G. C. (2017). *Stocktake of measures for mitigating the incidental capture of seabirds in New Zealand commercial fisheries*. Report to Southern Seabird Solutions Trust, Dunedin, New Zealand. 102 p. Retrieved from https://www.catchfishnotbirds.nz/post/stocktake-of-mitigation-measures

Phillips, R. A.; Gales, R.; Baker, G. B.; Double, M. C.; Favero, M.; Quintana, F.; Tasker, M. L.; Weimerskirchi, H.; Uhart, M., & Wolfaardt, A. (2016). The conservation status and priorities for albatrosses and large petrels. *Biological Conservation*, *201*, 169–183.

Pierre, J. P. (2018). *Mitigating seabird captures during hauling on smaller longline vessels*. Final Report prepared by JPEC for the Conservation Services Programme. 47 p. Wellington, New Zealand: Department of Conservation.

Pierre, J. P.; Abraham, E. R.; Richard, Y.; Cleal, J., & Middleton, D. A. J. (2012). Controlling trawler waste discharge to reduce seabird mortality. *Fisheries Research*, *131–133*, 30–38. doi:10.1016/j.fishres.2012.07.005

Pierre, J. P.; Gerner, M., & Penrose, L. (2014). Assessing the effectiveness of seabird mitigation devices in the trawl sectors of the Southern and Eastern Scalefish and Shark Fishery in Australia.

Plencner, T. (2023). *Liaison programme annual report*. Final report for MIT2021-01. Department of Conservation. 44 p.

Sacchi, J. (2021). *Overview of mitigation measures to reduce the incidental catch of vulnerable species in fisheries*. 136 p. Retrieved from https://www.fao.org/3/cb5049en/cb5049en.pdf

Sanders, B. M. & Fisher, D. O. (2022). Database documentation for the Ministry of Fisheries Centralised Observer Database. *NIWA Fisheries Data Management Database Documentation Series*.

Sullivan, B. J.; Brickle, P.; Reid, T. A.; Bone, D. G., & Middleton, D. A. J. (2006). Mitigation of seabird mortality on factory trawlers: Trials of three devices to reduce warp cable strikes. *Polar Biology*, *29*, 745–753.

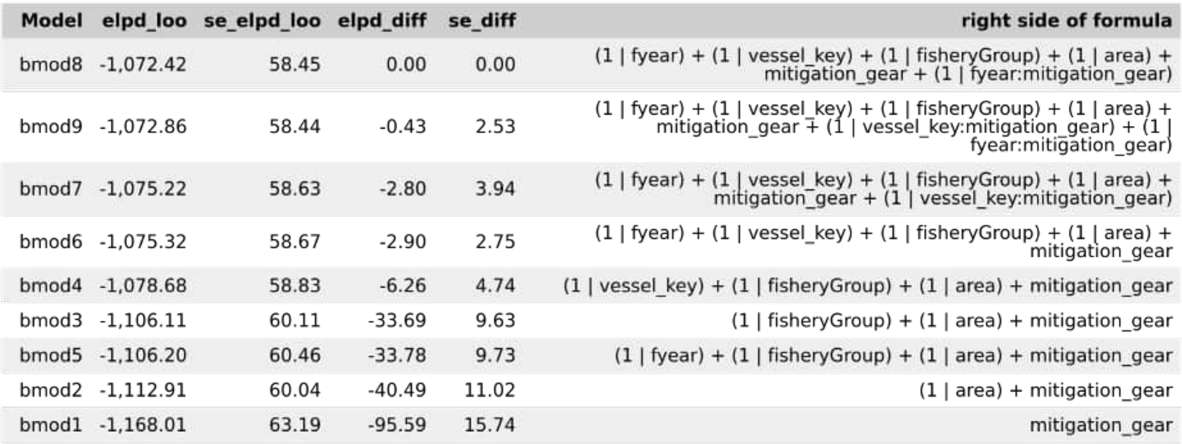
Tamini, L. L.; Chavez, L. N.; Góngora, M. E.; Yates, O.; Rabuffetti, F. L., & Sullivan, B. (2015). Estimating mortality of black-browed albatross (*Thalassarche melanophris*, Temminck, 1828) and other seabirds in the Argentinean factory trawl fleet and the use of bird-scaring lines as a mitigation measure. *Polar Biology*, *38*, 1867–1879.

Tamini, L.; Dellacasa, R.; Chavez, L.; Marinao, C.; Góngora, M.; Crawford, R., & Frere, E. (2023). Bird scaring lines reduce seabird mortality in mid-water and bottom trawlers in Argentina. *ICES Journal of Marine Science*, fsad109.

Vehtari, A.; Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, *27*, 1413–1432.

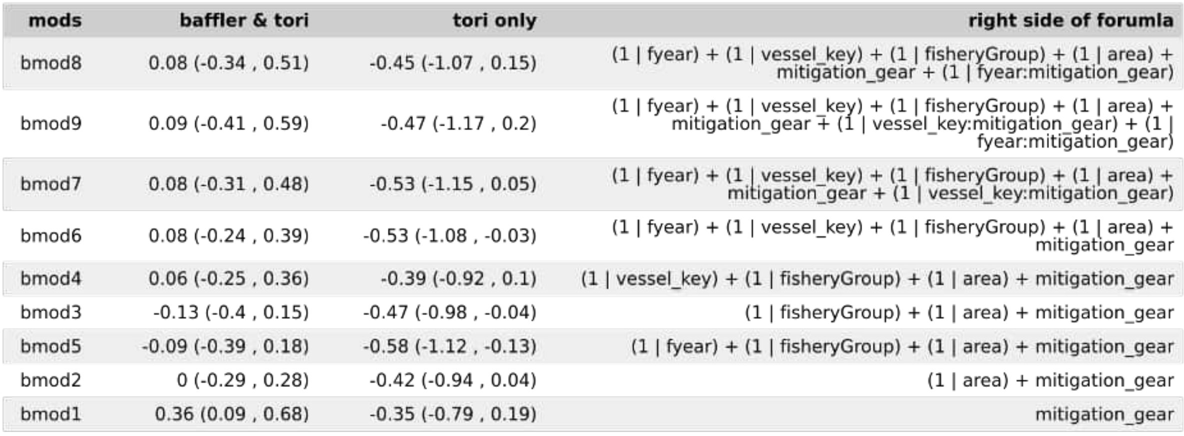
Weimerskirch, H.; Capdeville, D., & Duhamel, G. (2000). Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the kerguelen area. *Polar Biology*, *23*, 236–249.

## APPENDIX A: Model selection and parameter estimates



| Model | elpd_loo | se_elpd_loo | elpd_diff | se_diff | right side of formula |
|---|---|---|---|---|---|
| bmod8 | -1,072.42 | 58.45 | 0.00 | 0.00 | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear + (1 \| fyear:mitigation_gear) |
| bmod9 | -1,072.86 | 58.44 | -0.43 | 2.53 | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear + (1 \| vessel_key:mitigation_gear) + (1 \| fyear:mitigation_gear) |
| bmod7 | -1,075.22 | 58.63 | -2.80 | 3.94 | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear + (1 \| vessel_key:mitigation_gear) |
| bmod6 | -1,075.32 | 58.67 | -2.90 | 2.75 | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod4 | -1,078.68 | 58.83 | -6.26 | 4.74 | (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod3 | -1,106.11 | 60.11 | -33.69 | 9.63 | (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod5 | -1,106.20 | 60.46 | -33.78 | 9.73 | (1 \| fyear) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod2 | -1,112.91 | 60.04 | -40.49 | 11.02 | (1 \| area) + mitigation_gear |
| bmod1 | -1,168.01 | 63.19 | -95.59 | 15.74 | mitigation_gear |

**Figure A-1:** Models, ranked from the highest to the lowest performance in terms of expected log-posterior density (elpd) leave-one-out (loo) criterion, with associated standard error (SE), and elpd difference (diff) and associated standard error.



| mods | baffler & tori | tori only | right side of forumla |
|---|---|---|---|
| bmod8 | 0.08 (-0.34 , 0.51) | -0.45 (-1.07 , 0.15) | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear + (1 \| fyear:mitigation_gear) |
| bmod9 | 0.09 (-0.41 , 0.59) | -0.47 (-1.17 , 0.2) | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear + (1 \| vessel_key:mitigation_gear) + (1 \| fyear:mitigation_gear) |
| bmod7 | 0.08 (-0.31 , 0.48) | -0.53 (-1.15 , 0.05) | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear + (1 \| vessel_key:mitigation_gear) |
| bmod6 | 0.08 (-0.24 , 0.39) | -0.53 (-1.08 , -0.03) | (1 \| fyear) + (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod4 | 0.06 (-0.25 , 0.36) | -0.39 (-0.92 , 0.1) | (1 \| vessel_key) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod3 | -0.13 (-0.4 , 0.15) | -0.47 (-0.98 , -0.04) | (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod5 | -0.09 (-0.39 , 0.18) | -0.58 (-1.12 , -0.13) | (1 \| fyear) + (1 \| fisheryGroup) + (1 \| area) + mitigation_gear |
| bmod2 | 0 (-0.29 , 0.28) | -0.42 (-0.94 , 0.04) | (1 \| area) + mitigation_gear |
| bmod1 | 0.36 (0.09 , 0.68) | -0.35 (-0.79 , 0.19) | mitigation_gear |

**Figure A-2:** Model estimates and 95% credible interval (in parentheses) by model for the two levels of mitigation gear. The latter was the combination of baffler and tori lines and tori lines only; baffler only was used as the reference level at 0. Parameter estimates of less or greater than zero indicated a seabird capture rate less or greater than the rate for the baffler only, respectively.

## APPENDIX B: Model diagnostics

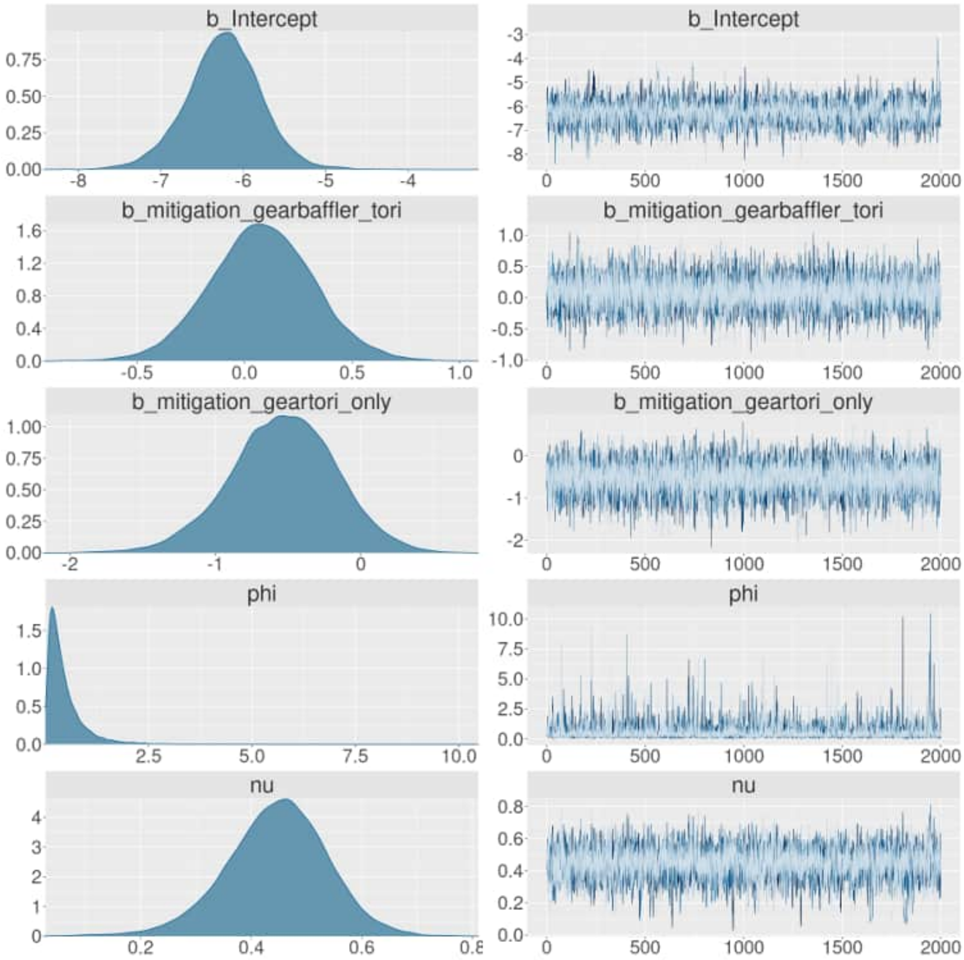


**Figure B-1:** Markov Chain Monte Carlo (MCMC) traces for 8 concurrent chains (right panels), with resulting posterior densities derived by combining all 8 chains (left panels), for key parameters in Model 8 for estimating the relative effectiveness of warp mitigation gear.

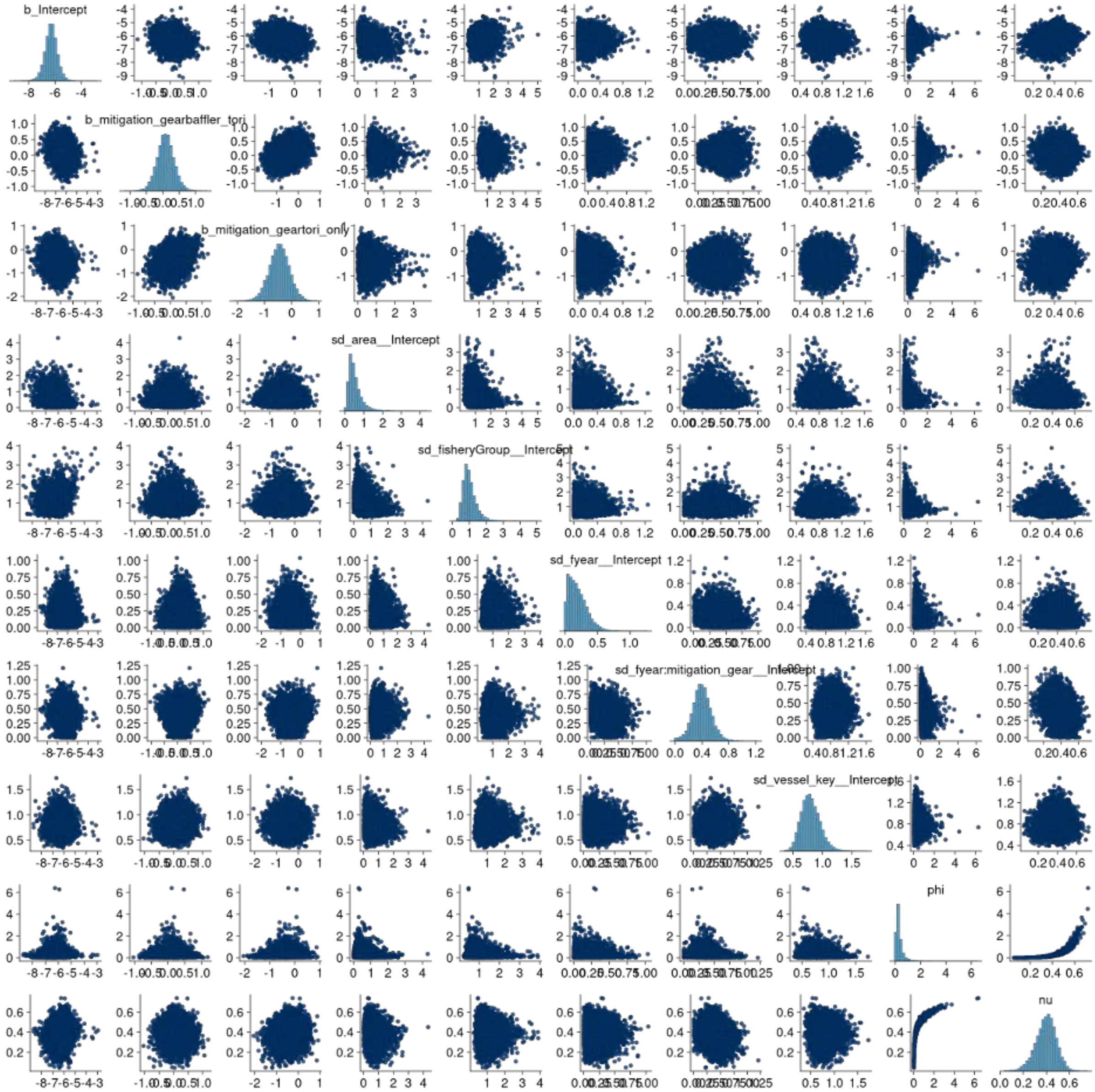


**Figure B-2:** Posterior distributions and correlation of Markov chain Monte Carlo (MCMC) draws across model parameters in Model 8 for estimating the relative effectiveness of warp mitigation gear. Strong correlation between the over-dispersion (phi) and scaling parameter of the over-dispersion (nu) are expected for this model.

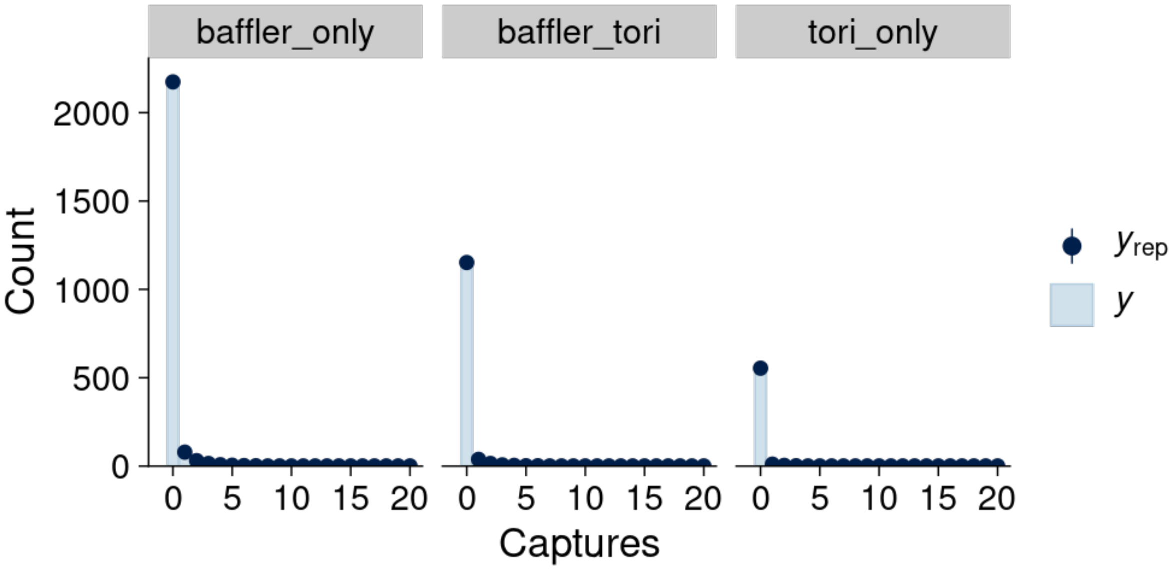


**Figure B-3:** Posterior predictive model diagnostic for Model 8 for estimating the relative effectiveness of warp mitigation gear. Shown are expected numbers of captures by mitigation device category in the model as predicted by the best model (black dots), compared with the data (blue bars). Mitigation device types were bafflers only, the combination of bafflers and tori lines, and tori lines only.